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1817

GEOLOGICAL SURVEY OF MICHIGAN
LUCIUS L. HUBBARD, STATE GEOLOGIST

UPPER PENINSULA

1893-1897

VOL. VI

PART I. ISLE ROYALE
ALFRED C. LANE

PART II. KEWEENAW POINT
WITH PARTICULAR REFERENCE TO
THE FELSITES AND THEIR ASSOCIATED ROCKS
LUCIUS L. HUBBARD

THE CRYSTALLIZATION OF THE CALCITE FROM THE COPPER MINES
OF LAKE SUPERIOR
CHARLES PALACHE

PUBLISHED BY AUTHORITY OF THE LAWS OF
MICHIGAN
UNDER THE DIRECTION OF
THE BOARD OF GEOLOGICAL SURVEY

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To the Honorable, the Board of Geological Survey of Michigan:

Gentlemen—Herewith I transmit Reports, with maps and illustrations, covering work done by the State Geological Survey in the Upper Peninsula, principally during the years 1895 and 1896.

With great respect, I am your obedient servant,

LUCIUS L. HUBBARD,
State Geologist.

GEOLOGICAL SURVEY OF MICHIGAN

VOL. VI

PART I

GEOLOGICAL REPORT
ON
ISLE ROYALE
MICHIGAN

BY

ALFRED C. LANE

Assistant State Geologist

ACCOMPANIED BY SIXTEEN PLATES AND TWENTY-NINE FIGURES
INCLUDING MAP IN COVER

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ERRATA

PART I

Page 5, 19th line from the bottom, for "McCullough" read "McCulloch."

Page 18, the first paragraph of the foot note belongs properly after the first paragraph of the text.

Page 19, 16th line, for "47" read "22."

Page 21, 11th line, for "dicovered" read "discovered."

Page 26, 16th line, for "Stockley" read "Stockly."

Page 41, 4th line, for "fault" read "faults."

Page 42, 3d line, before "mere" insert "a."

Page 74, 16th and 23d lines, for "tufa" read "tuff."

Page 74, 2d line from the bottom, for "Richey" read "Richie."

Page 94, 20th line, for "tufa" read "tuff."

Page 104, 3d line, for "tufa" read "tuff."

Page 105, table, for "Agate River" read "Agate Bay."

Page 105, over the columns headed "Conglomerate numbers" and "Distances" should be inserted "Portage Lake District."

Page 132, 9th line in explanation of figure 17, for "bottom" read "margin."

Page 134, 5th line in explanation of figure 18, for "130" read "124."

Page 149, 2d line from the bottom, for "increases" read "increase."

Page 168, 8th line from the bottom, *dele* "14748."

Page 185, 3d line, for "flow" read "floe."

CHAPTER I

HISTORICAL INTRODUCTION

§ 1. Prehistoric Mining.

The progress of knowledge is like the growth of a coral reef; each generation builds upon that which has been left behind by those who have gone before. It is, therefore, fit that this account of the geology of Isle Royale, a part of Michigan hitherto practically untouched by the State Geological Survey, should begin by a review of the records of what others* have in the past done toward its geological development.

The first mining upon Isle Royale was long before the arrival of the white man. Like other parts of the copper region about Lake Superior, Isle Royale was visited by tribes contemporary with the mound builders, and sheets of native copper were worried out of the rocks in which they were found enclosed. The hammers used in this work were hard pebbles. Specimens of these hammers found upon Isle Royale were not grooved for a withe, which might be twisted around them for a handle. In this respect they differ from those found on the south shore of Lake Superior. Such is the testimony of W. W. Stockly, Jacob Houghton, Dr. Simonson, Capt. Wm. Uren, B. Livermore, S. W. Hill and others, who have spent much time on the island, and their statements are confirmed by my own observation, as far as it goes. Winchell, however, says that occasionally and exceptionally one is found grooved, and figures one found on Isle Royale which belonged to Dr. Gailey. On Isle Royale they must certainly have been most exceptional. Swineford also mentions grooved hammers from Isle Royale.

---

*Jackson, Executive Documents, No. 1, 1849, First Session, Thirty-first Congress, p. 371. Hereafter cited as "J."

Foster and Whitney, Report on the Geology and Topography of a portion of the Lake Superior Land District in the State of Michigan, 1st Sess. 31st Con., Ex. Doc. No. 69, 1850, Pt. I, p. 162. Hereafter cited as "F. & W."

Gillman, Henry, "Ancient Works at Isle Royale, Michigan." Appleton's Journal, Aug. 9th, 1873, X, p. 173, "Mound-Builders and Platycnemism in Michigan." Smithsonian Report, 1873-74, p. 364, 1st Sess. 43rd Con. "The Ancient Man of the Great Lakes," Proceedings of American Association for Advancement of Science, 1875, B., p. 316-330.

Winchell, N. H., 9th Annual Report Minn. Geological Survey, 1880, p. 162; 10th Annual Report Minn. Geological Survey, 1881, pp. 48-54; 14th Annual Report Minn. Geological Survey, 1885, p. 322; Popular Science Monthly, Sept., 1881, XIX, V, p. 601.

Swineford, A. P., Annual Report of Commissioner of Mineral Statistics, Michigan, 1884, p. 8.

Sherzer, Will H., "Platycnemic Man in New York," Report of State Geologist, New York, 1894, p. 663.

It is probable, from the abundance of charcoal and half burned sticks that were found near the "Indian pits," that fire setting was practiced by these miners, that is that the rock adjacent to the copper was caused to crumble by dashing cold water on it suddenly, after having heated it very hot. It was then shoveled away or farther pounded with the stone mauls above spoken of. Then the copper in its turn was pounded off and fashioned into various instruments, axes, knives, arrow- and spear-heads, etc. These early workings were exceptionally abundant about the Minong mine and will be farther referred to when we come to the history of that mine (§ 3), but they also occur at the extreme northeast of the island on Blake Point,* and on a little island off Washington Island at the extreme southwest end of the Isle Royale archipelago, for the main island is fringed with more than a hundred and fifty smaller islets, and innumerable minor rocks.

These workings are prehistoric. By this we mean, that while they may well have been contemporary with Greek or Asiatic civilization, they were not being worked by the aborigines when the first hardy Jesuit missionaries penetrated into these regions, but were then already covered with a growth of forest.† Gillman thinks that they may have been abandoned seven or eight hundred years ago, judging from the size of the stumps of decayed trees. The works, however, were, as Winchell says, later than the glacial period, and later than the period of lakes much larger than the present, that immediately followed it, as they come down to within thirty feet of the present water's edge, or, according to Gillman, to within less than eighteen feet of it. Now Isle Royale, from one end to the other, shows evidence of a recent emergence from Lake Superior. This evidence consists in raised beaches, over which barely more than lichens have grown, in cascades falling into the lake, and in other marks. Hence no very great age can be assigned to the end of these workings. Winchell thinks that the miners and mound builders were the aborigines found here by the first discoverers, in other words, the Indians, and quotes a large number of references to the possession of copper by the Indians, and their use of it and knowledge where it occurred. So, also, Foster and Whitney quote from Father Dablon, in a "Relation" for 1669-1670, an account of " Menong," celebrated for its copper, and there is also an account of gathering copper there. Pierre Boucher in 1640 speaks of a mine of copper on an island in Lake Superior (Swineford, *loc. cit.*, p. 8). If we agree with Winchell that the miners were the Indians, we must suppose that the contact with European civilization, and the introduction of iron, made the early and laborious copper mining unprofitable, and that these early copper mines shut down for the same economic reasons which shut down mines at present. A very curious fact is reported, that none of the bones of the ancient miners have been found (Swineford, *loc. cit.*, p. 9), though the fish scales of their noonday lunches, their wooden bowls and implements, and even a bit of knotted rawhide have been preserved. Can we imagine that mining of copper was a prerogative of some class of medicine men who visited the island only at intervals? The possession of copper implements must have been at one time a coveted privilege. The question of the true nature of the earliest copper miners is, however, only a branch of the general question as to the character of the mound builders, which is likely to be settled by researches elsewhere, and is complicated with various considerations, as to the racial value of platycnemism, etc., that would carry us too far from our subject. Therefore, leaving the above references with those who desire to pursue the subject farther, we pass on to the historic epoch.

---

*F. and W., l. c., p. 162.

†Henry Gillman, Smithsonian Report, 1873-1874, p. 386.

§ 2. Earliest Historic Explorations, 1844-1855.

With the ending of the copper mining just described Isle Royale seems to have been abandoned, except by occasional trappers and fishermen,* though some report of its mineral wealth is said to have reached Franklin, perhaps through the Jesuit "Relations" and through his French friends, and to have led him in making the treaty with Great Britain which defined the limits of the United States, to curve the boundary line slightly so as to take Isle Royale and separate it from the Canadian shore, nearest to which it lies. The earliest explorations for copper were on the other side of the lake, and I have no record of mining or geological exploration on the island until after its cession with other lands, by the Chippewas in 1843.* Soon after this, prospectors appeared on the island, among them, in 1845, the veteran geologist, James Hall, who gave Chippewa Harbor its name and who was nearly caught on the island by the approach of winter, and crossed the lake in a small, open boat.† In 1846 explorations began and by 1847 the island presented perhaps as lively a scene as ever in its history. The U. S. Linear Survey was being pushed by William Ives and his assistants. I cannot let Ives's name go by without especial note as to the fine character of the work he did. Working far from civilization, through an extremely rough and densely wooded country, with an enormous amount of lake meandering, as will be obvious from the map, he turned out work far surpassing that customary on the Linear Survey, which has never been properly appreciated because never properly worked up, the map in this report being the first in which his notes have been computed and platted. This map is the work of Mr. W. W. Stockly. In the same year the U. S. Geological Surveyor, C. T. Jackson, made his first visit to the island with Messrs. Ransom, Peabody, Foster, etc. The margin of the island was then dotted with explorations, which within ten years were all closed. Let us review them briefly, beginning at the southwest end of the island.

---

*The Hudson's Bay Co. had a station on the island, Sec. 24, T. 64, R. 37, and the American Fur Co. one at Sec. 35, T. 64, R. 37; (J. 427), and near Card Point and perhaps on Fish sland, Sec. 35, T. 66, R. 34; Hulbert's map.

On Washington Island (referred to by Foster and Whitney and others, as Phelps Island), the Ohio and Dead River Company had Isaac Hewitt and Mr. Wright, an English miner, at work (J., p. 426) on three veins of only an inch wide, composed of datolite, compact feldspar and prehnite, containing a little native copper. Strike N. 17° E.; dip 75° W. Compare Jackson's map. These were on the north side. By the next year, when Dickenson and McIntyre visited the region, the place seems to have been abandoned (J., p. 506). Foster and Whitney (F. & W., p. 91) also mention veins on the southeast shore (Sec. 10, T. 63, R. 39) containing calcite, prehnite and native copper, and striking S. S. E., 18 inches wide. Farther east was another vein of great power, 30 inches wide and striking nearly north (dip 78° N. ? J., p. 770), with quartz, laumonite and prehnite, and disseminated copper, and on the S. E. ¼ of the same section another copper-bearing vein well defined, 7 inches wide.

---

*F. and W., p. 15, and J., p. 1157.

†Private communication.

At Huginnin (J., text, p. 425, Huganon; map, Huganin; F. and W., p. 90, Hugennin) Cove, Sec. 19, T. 64, R. 38, was an exploration of the Isle Royale and Chicago Company, soon abandoned.

Farther along the shore in Sec. 11, of the same township, was the Franklin Company (J. B. Corey, agent), working on some small veins of copper, striking north, and two of them 4 to 6 inches wide. These were also soon abandoned (J., p. 425).

On Sec. 33, T. 65, R. 37, the Siskowit Company had a location in charge of Chas. Whittlesey, the same who had charge of the Siskowit mine.* This was on some small veins and soon abandoned (J., p. 425). Passing over the veins near by, described by Jackson (p. 425), which do not seem to have been worked upon, we come to the Pittsburg and Isle Royale Company's location at Todd Harbor. This was one of the most important openings of the time, and was still worked when Koch visited it in August, 1850, and the traces of the old workings were still very plain when I visited the region in 1893. Foster (J., p. 770) also speaks of McCullough's working at the outer point of Todd Harbor. The works lie near the harbor and are in and near the lower side of that group of rocks that I propose to call the Minong trap, since it underlies the Minong mine, later to be described (p. 16). These rocks are more acid, as is shown by the less development of augite, than the flows above and below (see Chap. III), and answer well to Foster and Whitney's description of "hard greenstone with a conchoidal fracture," the clean fracture being especially characteristic at the bottom. The main location was on Sec. 12, T. 65, R. 36 (F. and W., p. 150). The first working that Jackson examined (J., p. 424) was a stockwerk without any well defined walls, thus resembling the occurrence at the Minong mine. The veinstone he says was an amygdaloid containing laumonite, calcite, datolite, and native copper, the metal occurring in pieces of a pound weight. This copper-bearing rock was 15 feet wide and in general sloped to the north.

Another vein was 7 to 8 inches wide; strike N. E. and dip to N. W. 65°. In a third place was a vein a foot wide, bearing thin sheets of copper. Strike N. 25° E., dip to N. W. 74°. As is often the case, the wall rock "is shivered into a shingle of slaty appearance, and is disintegrated for the width of four or five feet." This last vein is probably also given by Foster and Whitney as the lode with a strike N. 20° E., dip W. 78° (p. 150). Foster and Whitney also seem to allude, on pages 150 and 169, to another vein running north and dipping to the east. They describe two shafts, 63 and 67 feet deep, with the first adit or level 42 feet long, the second 113 feet, the third 18 feet, fifty tons of ten per cent ore raised, and twenty-four men employed. In the following summer, July, 1848, the mine was again visited by Dr. Jackson's agents, who in substance reported (J., pp. 505, 509): There were then nine men employed. Three veins were worked, two a short distance from the one (!) worked last season. After drifting on that vein some 30 feet the copper disappeared. A shaft was then sunk a short distance north of this drift, and in sinking 5 or 6 feet, a blue earth was struck filled with copper in the form of shot. This bed was 5 to 6 feet thick and below this there was a red colored rock filled with spar, but it contained no copper. Then they drifted 60 feet from the edge of the lake on a vein 2½ feet wide, with well defined walls dipping W. 70°. One sheet of copper was exposed, 8 feet long, 4 feet high and 1 to 2 inches thick.

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*See below.

West of this vein (No. 3) a shaft was being sunk on a small spar vein with some copper. There was still another vein east of the agent's house, which ran north (No. 4). The agent sank a shaft on this vein so near the lake that the water compelled him to abandon it, and then he went farther inland and sank a shaft, and also struck a small spar vein running east. James McIntyre (J., p. 509) gives vein No. 3 as striking N. N.E., dipping 70° W., and mentions that they are sinking a shaft from the top of the hill to strike the drift.

In August, 1850, the island was visited by the German mining engineer, Fr. C. L. Koch, who found only the Todd Harbor and the Siskowit works still in operation. He gave to the world the observations that he made on his trip, in Vol. VI, parts 1 and 2, of the "Studien des Goettingischen Vereins Bergmænnischer Freunde," 1852, and I will translate from this rare report that part which refers to Isle Royale. The map accompanying is a copy of that of Foster and Whitney, with the original misprints retained, and others added (Amyghaloid Island for Amygdaloid Island, Loke's Point for Locke's Point, etc.).

"Todd's Harbor,* Pittsburg and Isle Royale Company, on the northerly shore of the island, opposite Canada. The company has undertaken several exploratory openings here, of which one was in operation when I was there (1850), close to the lake, probably only 20 feet above the surface of Lake Superior. The wall rock consists of a close grained, crystalline, dark amygdaloid, which may be considered as a transition to a close grained or compact trap. The vein stands in this, striking from south to north, and as it appears, dips tolerably vertical. So far as the vein is yet known, it is not very wide. The vein-rock is here a compact chloritic mass, with quartz, calcite, and prehnite, which minerals occur in small druses with a tendency to crystalline form and also as complete and beautiful crystals. Beside these I also noticed associated with calcite the reddish yellow feldspathic mineral, and small but very beautiful apophyllite crystals. I also found small copper crystals here.

"The product of good stamp copper appeared to be not inconsiderable and will be made manifest as soon as the stamp mill begins work, which is in process of construction (which will take its water for motive purposes [?] or for jigs, ["Aufschlagwasser,"] from a little stream which forms a beautiful waterfall on the margin of the lake near the mine). Some barrels of the coarser masses of copper, some of them weighing several pounds apiece, were packed for shipment. The mine was manned with only a small force, and it was uncertain whether the vein was to be explored to a greater depth. It would be regrettable if the company should withdraw their capital from this locality; it deserves, at any rate, a still closer investigation." Page 201, trap contains augite and labradorite; p. 202, epidote replaces the augite and quartz the feldspar; p. 205, copper; p. 213, apophyllite at Todd Harbor (with copper crystals and prehnite); p. 217, prehnite at Todd Harbor; p. 219, epidote (thallite).

The first shaft that I saw on my visit in 1893 was nearly vertical and 30 to 40 feet deep. It was in a light green seam with a little copper in a compact, slightly mottled trap. About 100 feet northeast the openings on vein No. 3 are well marked; strike S. 25° E., dip 75° W.; and at the water's edge there is an adit connected with the opening. This seam, and joints parallel to it, intersect a laumonite seam which is nearly parallel to the formation (strike N. 50° E., dip 54° to S.E.), without displacing it. The seam is about 300 feet from the ten foot fall mentioned by Koch, which does not come in at the lowest point of the shore, and is a significant index of the recent changes of lake level.

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*Pp. 188, 189.

Continuing northeast, the next location visited by Jackson (p. 424) was that of Mathewson Miller, (J., p. 770) or, as Ives called it in his field notes, the Amygdaloid and Isle Royale Mining Company, Sec. 23, T. 66, R. 35, where the main vein had a strike to east, dip to north, was 2 feet wide, and had yielded about 30 pounds of copper. Another vein near by had a strike N. 60° E.; dip to north. This is opposite Hawk Island, and just north of the Minong mine.

On Amygdaloid Island (J., p. 423), claimed by Miller and the American Exploring Company, was a vein of little value, dip 48° to N. by E.—epidote with a little copper. Neither of these locations is again mentioned.

Of Duncan's explorations, on Secs. 27, 28, 33 and 34 of T. 67, R. 33, on Duncan Bay, about three-quarters of a mile from Monument Rock, nothing more is written (J., p. 423), unless Foster and Whitney, in their reference to the Duncan vein on Sec. 34, T. 66, R. 34, have made a slip and really refer, as I am inclined to suspect, to T. 67, R. 33 (F. and W., p. 169). They were doubtless soon given up.

Coming to Scovill Point, we find once more comparatively siliceous traps, having passed around Blake Point, which marks one end of the great range of basic lustre-mottled melaphyres, or as Foster and Whitney call them, varioloid greenstones, which form the "backbone" of the island. The more acid beds lying above correspond to those lying around the "Ashbed" on Keweenaw Point, as will be later shown, and like them are much more inclined to a fine grained texture, with basaltic jointing, and a cleaner conchoidal fracture, as mentioned by Foster and Whitney (p. 82-83). Here, on the "forefinger" (J., p. 770) of the island, Scovill Point, Jackson found Scovill (J., pp. 422, 423, 505; F. & W., pp. 83, 169, 171; both spell the name without the final e) on Sec. 35, T. 67, R. 33. The vein on which he was working was from 1 foot 3 inches to 2 feet 6 inches wide, with some lateral string veins or leaders, containing a greenish mixture of calcite, prehnite and trap, and sheets and spicules of native copper. The strike was N. 65° E., dip 68° to N.

W. (J., p. 422). By the next year, when Dickenson visited it, there was but one man left, and but little had been done in the interval. Only a shallow pit was opened. A marked ravine and "fossa" are said to indicate a continuation of this vein to the southwest, according to Foster and Whitney, nearly nine miles. This may possibly be so, but the strike of the vein as given is nearly that of the formation, which dips off to the southeast at an angle of about 17°, and from my observations I should say that Scovill Point was made up of two flows of trap (J., p. 770) and that the hollow, running as Jackson says, by solar compass N. 61½° E., var. 6½° E., marked the line of contact of the two beds with associated amygdaloids.

Shaw's or Smithwick's location, the next met, was on Sec. 4 and perhaps also Sec. 3, T. 66, R. 33, directly opposite to Smithwick's Channel, about 100 rods southwest of Scovill's, along the line or vein mentioned above. The deposit there was similar to Scovill's, and contained some specks of silver. In 1848 there were three men there and the shaft was down 90 feet (J., pp. 422, 505). By 1849 (J., p. 605; F. and W., p. 171) it was down 96 feet. For 30 feet the rock was soft, the vein well developed, expanding in places to 4 feet in width, and containing considerable copper. Then a band of columnar trap was struck and penetrated 66 feet. The vein contracted to a foot in width and was nearly worthless. This columnar trap appears, according to Foster, in the point north of Scovill Point, at the water's edge, and continues in a cliff on the north side of the point, 30 to 40 feet high (J., p. 770). Mr. Shaw (F. and W., p. 171) had a similar experience on the main point, Sec. 33, T. 67, R. 33, where he sank 15 feet on a vein composed of quartz, chlorite and calcite with considerable copper (strike N. 50° E.), where on passing from a crystalline trap with feldspar to a darker trap, the vein became worthless.

On Mott Island, Jackson (J., p. 422) saw a small copper vein, 4 inches wide; strike N., 80° E., dip 50° to N. The veinstone is 2 feet 4 inches wide, but is not all metalliferous.

The next location was, we believe, the most enduring of any of those worked in 1847, as well as one of the first opened. Called by Jackson the Union Company, its permanent name was the Siskowit mine. Chas. Whittlesey, a cousin of the prominent writer, Col. Chas. Whittlesey, of Wisconsin, came up in the Julia Palmer (the first steamer on Lake Superior) in October, 1847 (with Mr. John Senter), to take charge of the explorations, and wintered there. Under him was Mr. Jas. Hubbard. The explorations were on Sec. 13, T. 66, R. 34. The vein Jackson (J., p. 421) found to be 5 feet wide, the copper mainly in sheets in contact with the walls of the vein, which is well defined. Veinstone (F. and W., p. 150) was epidote, chlorite and calcite, with copper disseminated and in sheets and masses,—the largest mass (F. and W., p. 143) 350 pounds; strike N. 88½° W., dip N. 82°, or, according to Foster and Whitney, 75°. Jackson also noticed (J., p. 421) three small veins which traversed these rocks. Next year Dickenson found a 40 foot shaft, and a 90 foot drift, with about 40 tons of ore (J., p. 505). In 1849, Foster and Whitney reported two shafts, respectively 40 feet and 35 feet deep, and 115 feet of drifting. As at Shaw's location, just described, 35 feet to 40 feet below the surface the vein passed from an overlying amygdaloidal trap (F. & W., p. 171; p. 150, dark, compact trap) to a columnar bed in which the vein was badly pinched. In August, 1850, Koch visited the mine, and we translate his description:—(*loc. cit.*, p. 185.)

"1. Siskawit Mining Company, Town 66, Range 34, Sec. 13, situated on the south [*sic*] shore of Rock Harbor. The principal strike of the trap ridges of the island is from southwest to northeast. The deposit worked by this company strikes from east to west and dips about 35° to the N. E. It crosses the trap rock, therefore, at an angle of about 45°. The principal rock in which the copper occurs is of a chloritic nature, more or less solid, possibly as there is more or less siliceous matter mixed with it; it assumes an amygdaloidal character near the country rock and finally passes into an amygdaloid, which has, however, a tufaceous ["blattersteinartiges"] appearance, owing to various kinds of crystalline secretions, especially of calcite. I have not been able to perceive distinct selvages, but at many points one can distinguish the chloritic rock-mass from the country rock. This copper lode is about 2½ feet thick, but the copper has penetrated into the foot- and hanging-wall beyond and outside of it. At many points the copper occurs in thin plates, which now and then thicken to larger pieces, up to several pounds in weight. It occurs less often in thick lumps. Not rarely we find in the chloritic mass small druses with crystalline copper, transparent colorless ["hellen weissen"] calcite crystals, and other small crystals of a feldspathic mineral of yellowish and reddish yellow color. Whether another mineral which occurs in indistinct crystals belongs to the zeolite family (perhaps analcite) I shall not venture to decide.

"Since the mine furnishes principally stamp rock, the steam engine just put in place, by which the stamp mill, etc., are to be run, will meet one of the most pressing needs. Considerable of the coarser masses of copper had already been sold, and they figure on a product of about 30 tons up to the close of navigation. The elevation of the point where the mining is at present being pushed, above the lake level, is inconsiderable, perhaps only 30 or 40 feet; if one does not shortly have to fight too much with water, this field may perhaps give favorable results. At that time ten miners were employed, and thirty odd people in surface work."

The deposit seen by Koch seems to have been different from that visited by Foster and Whitney. The former is possibly the one mentioned by Foster and Whitney as 1,800 feet west of Shaft No. 2.

The Siskowit mine continued working until 1855. Capt. W. Tonkin, later of the Atlantic mine, was in charge from 1852 to 1853. He reported to Swineford (p. 10; the account below is based also on personal interviews with Capt. Tonkin and John Senter) that the work was done on two veins, the more easterly of which dipped to the west, thus corresponding to the one above described by Jackson and Foster and Whitney, and at the time Capt. Tonkin left, the shaft upon it was down to the sixth level. Afterward this shaft was sunk 100 feet more, to about 500 feet in all, but the vein was lost. The other, or west vein, was very nearly vertical and the shaft upon it was down to the third level. The mine produced about 150 tons of copper. Each vein carried some copper, and it was Tonkin's expectation that when they came together, as he expected them to do at about 600 feet, a good mine would be found. That depth was never attained. The white chimney of the old mine is still a conspicuous feature of Rock Harbor. My notes of the mine are as follows: The old dump extends to the water's edge; specimen No. 16282 represents the country rock trap, at the surface, while specimen No. 16283, from the dump, doubtless represents the columnar trap spoken of, being fine grained and black. About 100 feet northwest from the shore is the old stack, and immediately adjacent, the foundations of two old buildings are visible. Directly from these to the west are four old test-pits or shafts, extending for 400 feet or more, filled with water, on a vein striking north of east and dipping to the north 73°. About 150 feet farther northwest is another row of five or more pits on a vein apparently parallel to the last mentioned (strike N. 80° E.), and dipping perhaps very slightly to the north. It is obvious that, taking the dips as 90° and 75° (F. and W., p. 150), and the distance between the two veins as 100 feet, we get just the 600 feet which Tonkin spoke of as the distance at which they should meet. The trap ledges seemed to strike N. 49° E., and to dip 17° to the southeast. The elevation of the work was about 25 feet above the lake (see cross-section E-F, Pl. XIII).

On the next section adjacent, to the southwest (Sec. 23), were explorations of the Ohio and Isle Royale Company which seem to have been confused with those of the Siskowit mine just described (Swineford, p. 10; F. and W., pp. 143, 144, 150; J., pp. 418, 419, 505, 796). It is obvious from these references that Swineford is in error in saying that Foster and Whitney's report does not mention the Pittsburg and Isle Royale Company, nor the Siskowit Mining Company. It appears also that C. C. Douglass was the agent for the Ohio and Isle Royale Company, which had very numerous explorations in various parts of the island, and was distinct from the Union Company, afterward Siskowit Mining Company, which had Whittlesey as agent. The description of the location of the first explorations as one mile northeast of the main entrance to Rock Harbor, fits the Ohio and Isle Royale, but hardly the Siskowit mine. Swineford's doubt as to the furnace is also clearly unjustified, and he is also in error in saying that Foster and Whitney make no reference to the ancient diggings (F. and W., p. 162).

The rock is reported like that at the Siskowit mine and on the S. E. ¼ of Sec. 22, at 20 feet they struck the columnar trap again, the vein pinching from 3 feet to a mere seam, and it seems to have been taken as the same vein, which, considering the strike, it could hardly be, though very likely of the same system of veins.

Other similar openings were made by this company, on Sec. 23 and Sec. 27 adjacent, T. 66, R. 34 (F. and W., pp. 144, 171), and the latter section was the site of the town of Ransom, opened by Ransom and Reynolds in 1846, where quite a clearing was made. It is at the mouth of the stream draining Lake Benson. The explorations here were similar to those at the Siskowit mine, etc. (F. and W., p. 144). In 1847 the company had fifty men at work. After the preliminary work by Leander Ransom, in 1846, J. H. Blake seems to have had charge in 1847. During a large part of the summer of 1848, Mark Matthews, now (February, 1896) residing in Houghton, had charge, but he left the same summer, and soon afterward C. C. Douglass arrived with workmen to finish the copper furnace (priv. comm.; J., p. 505; F. and W., p. 144; Koch, p. 187).

In 1849, Messrs. Douglass, Whittlesey and Shaw were still at work in these regions (J., p. 506), but, as we have already remarked, in 1850 Koch found only the Siskowit mine still manned.

Other explorations of the Ohio and Isle Royale Company were on Sec. 34, or Sec. 35, T. 66, R. 34 (J., p. 428; F. and W., pp. 143, 144, 150, 169; priv. comm. of Mark Matthews, and personal observations). There are some puzzling misprints in Foster and Whitney about what I suppose to be this location. On page 143 they give quite a description of a vein on the S. E. ¼ of Sec. 34, T. 66, R. 34, which they say is about two miles south of Rock Harbor by the lake shore, so that an adit has been started near the water level to intersect a shaft 25 feet deep, a short distance from the shore. The same description is given on page 150, and again on page 169, where the vein is called the Duncan vein. This last name might lead us to think of the section whereon Monument Rock stands, the scene of Duncan's labors, but if so, both the town and range are wrong, and, besides, we have no other indication that the Ohio and Isle Royale worked in that neighborhood; nor is a mine indicated there on any of the maps.

On the other hand, if the town and range are right, the S. E. ¼ of Sec. 34 is more than a third of a mile from the lake in any direction and more than 25 feet above the lake, and has also no indication on the map of having been mined. (Jackson, to be sure, mentions, on p. 428, a vein at Conglomerate Bay, strike E. N.E., dip 85° to N., which might be in Sec. 34.) On Sec. 35, which is just adjacent, Foster and Whitney on their map indicate, by a sign which they use elsewhere only for the other two properties given in their table on page 150, a mine in operation, and Mr. Matthews remembers working in that region. Finally, on lot 5, of Sec. 35, I found traces of works corresponding to Foster and Whitney's descriptions

(Sp. 16318, 16319). There are on this lot a number of ruined shanties and remains of a shaft house in a little cove. Judging from the shaft, the vein might have had a strike of N. 65° E. and a dip of 57° to N. W. There seem to be rhombohedra of dolomite in the vein rock and cavities coated with prehnite on epidote. These works are not very far south of some old works on lot 4, that I suppose to represent the Saginaw mine (but C. LeSage, a boatman who has been off and on the island for many years, said the more southerly work was the younger), which was developed much later in the seventies, in similar rock. Foster and Whitney give strike N. E., dip to N. W. 68°, the country rock a dark gray granular trap capped with greenstone, the length of the adit 40 feet, and the product 10 tons of 9 per cent "ore."

On Sec. 2, T. 65, R. 34, near Lea Cove (J., p. 504) or Lucky Bay (Winchell, *loc. cit.*, 1881, p. 53) a shaft was sunk 40 feet (F. and W., p. 144). At the depth of 10 feet a belt of sandstone was struck which continued as far as the shaft was prosecuted.

On section 35, in the same town and range, another shaft is reported (F. and W., p. 144), 90 feet deep on a vein inclined to the northwest, the formation dipping to the southeast. But this location would be away out in Lake Superior! Should not the reference be to Sec. 35, immediately abutting on Sec. 2, on the north, i. e., in T. 66, and thus to the works already described?

On Sec. 10, T. 65, R. 34, close to the line between sections 9 and 10, where a little pond on Sec. 9 is almost immediately adjacent to the lake shore, are the works known as Epidote, which I have visited (F. and W., pp. 144, 169; J., pp. 418, 770).

This Jackson describes as five miles southwest of Rock Harbor in latitude 48° 2′ 8″ N. "The whole coast is composed of trap rocks, with two beds of epidote rock, the upper of which is full of native copper. The copper-bearing bed is about one foot in thickness, and consists of a yellowish green, granular epidote, filled with angular grains of pure metallic copper very uniformly distributed, and constituting from 8 per cent to 20 per cent of its weight. Under the copper-bearing bed there is another bed of epidote, more compact in structure, and about five or six feet in thickness. This bed contains stellated masses of a mineral which I named chlorastrolite." The lower bed of epidote was hard to drill. The dip of the copper-bearing bed was S. E. by S., 28°. Small true veins of datolite, calcite and prehnite, containing spicules and sheets of copper, were seen to traverse the trap rocks and cut through the epidote veins. (Dip 60° to N. W. by W.) Foster and Whitney allude to the deposit at Epidote as a bed.

The works are, of course, much overgrown and obscured now. Their location is shown on the map. The elevation is about 50 feet above the lake, and less. The material of the dumps—there are three distinct pits noticeable—is sandstone, often indurated and full of epidote and calcite. It is highly probable that the works are in the same belt of sandstone which was met in Sec. 2, and which also outcrops at Chippewa Harbor from beneath the outer wall of trap. The epidotic zone is its upper contact, where it has been altered through the influence of the overlying traps, as it is for about three feet below the traps at Chippewa Harbor.

The work at Epidote was done in 1846-8. The next location was called Datolite (J., pp. 427, 505; F. and W., p. 88), on Sec. 34, T. 65, R. 35, and was named from the abundance of datolite found there. There were two veins, (1) 2 feet wide, strike N. 60° E., dip 50° to N. W.; (2) a few inches wide, strike N. 35° E., dip to N. W. Native copper in rhombic dodecahedra occurred in them. The Ohio and Isle Royale Company were sinking a shaft in 1848, while the work begun in 1846 had been allowed to lapse in 1847. It is possible that the descriptions of F. & W., pp. 143-144, may refer to this, as they fit pretty well, instead of to Sec. 35 of the township next northeast.

§ 3. The Minong, Island and Saginaw Mines, 1871-1883.

We have thus been around the island and described the numerous openings which marked the period of activity which culminated in 1847-48, and rapidly waned until the closing of the Siskowit mine in 1855. Then the island was a desert once more, with no permanent inhabitants. Thus it remained for many years, so far as any scientific results were concerned, though of course there were visitors. So for example, Prof. A. Litton, of St. Louis, informs me that the eminent geologist, D. D. Owen, with himself visited the island in 1858, on their return from the famous trip preparatory to Owen's report on the geology of Minnesota, Wisconsin and Iowa.

In the meantime, especially during the war period,* the property was gradually becoming consolidated, until the North American

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*Swineford, loc. cit., p. 14.

Mineral Land Company came to own most of the island north of the sandstone area.

The revival of activity on Isle Royale may perhaps be dated from the arrival of the engineers of the Lake Survey (John C. Mallory, G. A. Marr, etc.), who were employed making a chart and map from 1867 to 1871. At that time no mining work was going on.* But in 1871, when the U. S. Engineers were almost through, and only three men were left flashing signals from the station back of Rock Harbor, explorers for the North American Mineral Land Company arrived on the island, who were under the general direction of S. W. Hill, among them B. Livermore, yet alive, who had been with Whitney, and had helped him ascend Monument Rock in 1849 and 1850. The explorations of these parties which were carried on very extensively over the island, resulted in two promising mines.

In 1871, in the fall, the old Indian diggings on the Minong range were found, first on a fissure vein crossing the high outcrop of the Minong trap. In 1872, a force of forty men were set exploring, with the result that there was disclosed an enormous amount of prehistoric mining on Sec. 26 and Sec. 27, T. 66, R. 35, between McCargoe Cove and Todd Harbor (Fig. 1.) Here the ungrooved cobbles that were used as hammers, could, it is said, be collected by the cartload. Some of the pits were 20 feet to 30 feet deep, and Capt. Uren tells me that in a stope 30 feet deep and 18 inches to 30 inches wide, boulders had been rolled in and wedged to take the place of timbering. There were drains for these pits, and in one case a drain 60 feet long had been covered by timber, felled and laid across.

As already mentioned, fire-setting had been employed, and a fragment of a wooden bowl about three feet across, and of a wooden shovel, and also of a rawhide string were discovered.

In May, 1873, the region was visited by Henry Gillman, whose account is referred to on page 2.

In 1874 a company was duly organized to work these old mines once more, under the name of the Minong Mining Company (Minong being the Indian name generically for island and applied specifically to Isle Royale). An area of some 1,445 acres was bought from the parent North American Mineral Land Company, for the purpose, including in T. 66, R. 35, west of McCargoe Cove, the western half of Sections 23, 26 and 35, and the eastern half of

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*Priv. comm. from J. C. Mallory.

T. 66 N., R. 35 W.

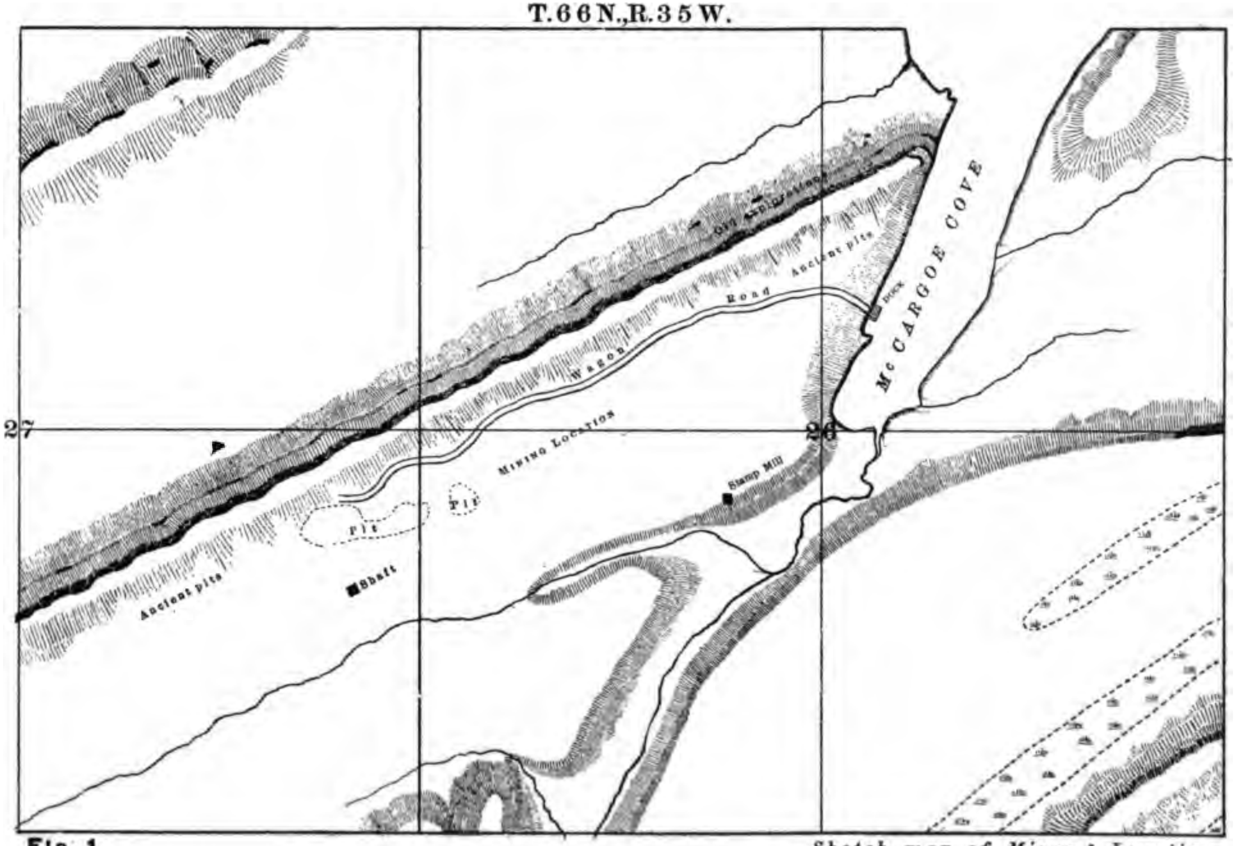

Fig. 1. Sketch map of Minong Location.

sections 22, 27 and 34. In 1874 a mass of copper weighing 5,720 pounds.*

In 1878 a mass weighing six tons was found, followed, in 1879, by two masses weighing respectively 3,317 and 4,175 pounds. The latter was about nine feet long. These large masses were buried, but there was a depression in the surface over them. In 1879 Winchell visited the island, and his published notes are found in the 10th Annual Report, Minnesota Geological Survey, and in the article above quoted in the Popular Science Monthly.

The first agent for the Minong Mining Company was A. Clayton Davis (Swineford says that he left at the end of the second year); H. Walker, of Detroit, President; E. W. Hudson, Secretary and Treasurer; Wm. Stevens, of Detroit, and John Senter, were prominent stockholders. Capt. Wm. Jacka was mining captain.

In 1876 a stamp mill was built, with a Ball's stamp, and is reported to have yielded, in 1876, 20.25 tons of "mineral" from

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(*Winchell, Pop. Sci. Monthly, Sept., 1881, p. 602) which had been worked upon by the miners, was found on the island with poles underneath it, and was exhibited in Detroit and at the Centennial Exhibition of 1876, and afterwards sold.

Letter of S. W. Hill, Dec. 19, 1874:

"Commencing at the harbor in section 26, there is a ridge of bedded diorite having a direction south 60° west; its length in this property is something more than one mile. This ridge is traversed by veins, the greatest number of which bear south 10° to 30° west; there are more than twenty in this property, the greatest number of them have been extensively mined by a pre-historic race.

"The depth of some of these old mines has been found to be sixty feet; where the veins have been uncovered, the excavations in them by the old miners, when cleaned out they have been found well filled with copper; one thousand feet west of the harbor, in Sec. 26, west half, there is a group of several veins; the works of the old miners mark their course more than twelve hundred feet, the veins are united in the north part of the ridge. The evidences are that these mines will pay to mine. They are of good width; other and large veins near this group that have been extensively mined have been found.

"The Witthaus veins in the east half Sec. 27, form another group in which the works of the old miners are as extensive as even the works of this kind in both Minnesota and National mines, on the south side of the lake; these veins are large and well defined, and will, I believe, be found to be of great value when mined."

Letter of A. C. Davis:

"The property has a number of transverse veins that show a large amount of ancient mine work. I cleaned out one of the ancient pits on a vein near the east line of section 27. Its depth was twenty-six feet. I found a vein two feet wide. I put in a blast, and the result was about forty pounds of barrel copper, besides stamp work. I consider this vein a valuable one to mine for copper, and the chances of getting a paying mine I regard as almost certain.

"The property has a sedimentary belt running through it that is highly metalliferous. This belt has also been extensively mined by the ancient miners. I cleaned out three of the ancient pits on this belt, distant one from the other nearly a mile, in all of which I found barrel and stamp copper in quantity to warrant mining. At one point I made a cross cut across this belt, and found it to contain copper for a width of forty feet. It was in this cross cut I found the mass estimated to weigh 6,000 pounds. This mass had been detached from its bed by the ancient miner. I found a number of pieces of copper besides the mass, weighing from an ounce to seventeen pounds. I did not do any blasting in the cross cut, but broke the rock with a pick in many places, and invariably found it well filled with copper."

1,579.50 tons of rock, or about 1 per cent copper. A diamond drill was also employed.

In 1879 there was a reorganization, the Minong Copper Company replacing the Minong Mining Company. Dr. Simonson, at present of the Calumet and Hecla Mine, went there as physician. Among the later agents were S. Brady, and Capt. Hodgson. Finally, in 1883, the mining was suspended, but in the meantime from 1881 to 1883 the mine had been taken on tribute by John F. Johns, Cribeau and others, who worked a while longer and are said to have done pretty well the first summer, finding a six ton mass and a number of smaller masses, making about $800 to $900 apiece.* In the report of the Commissioner of Mineral Statistics, however, the mine disappears as a producer in 1883. The information as to tributing is from memory and therefore unreliable. The statistics of production are given in the table with the Island mine and the Saginaw, page 47.

The extensive location of the Minong is now all gone to wreck and ruin, and has been pretty thoroughly plundered. We find the traces of old explorations, whether prehistoric or not, clustered along the fine-grained trap, the same belt around which McCulloch was working at Todd harbor. Here as there, too, the fine-grained black conchoidal trap is overlain by, and has apparently intrusive contact with a red, more acid rock (felsophyrite specimen No. 16,082 intrusive in 16,081 and 16,080A; Sp. 16,137-16,142, 16,155, illustrate the relations). Above this latter is a sedimentary bed of volcanic breccia.

This same acid rock is, as we shall see later, exposed around Todd harbor but a little way south of here. The acid felsophyrite encloses fragments of the darker rock and is evidently affected in composition by it. Along this contact the copper occurs in a sort of stockwerk, that is, in a number of irregular and ill defined veins running into one another all ways, and the workings have followed them most irregularly. As usual in the Isle Royale ranges the south slope is the gentler, and all over this slope in Secs. 26 and 27, T. 66, R. 35, are found pits and explorations, with a great many of the cobbles that have been used as hammers. The strike of the range from Todd harbor to McCargoe cove is about N. 61½° E., and the strike at the mine seems not far from 60°. The dip is about 20° to the south, and one shaft was put down following the dip and, probably in a general way, the contact of the intrusive rock. Some of Vaudrey's recollections of this shaft throw light on the general dip. According to him the diamond drill went down only 50 feet to 60 feet and got stuck, and they abandoned the bit. The drill hole was started about 200 feet from the dryhouse in lower ground, i. e., southeast of it. The inclined shaft ran southeast under the dryhouse and would have struck the drill, it was supposed, within 500 to 600 feet. The shaft went down 300 feet; the ground was stoped from 100 to 300 feet. The slope of the shaft is about 1:4 and the shaft is not 100 feet from the surface at a point under the old blacksmith shop, so that the sound of the sledges could be distinctly heard in the dryhouse. It appears, therefore, that the dip of this shaft harmonizes pretty closely with the general dip of the formation and was following the upper side of the Minong trap, and its contact with the acid rock (felsophyrite). The intimate relations of this acid rock with the underlying trap, which is itself not as basic as are the beds in this part of the series commonly, are hard to describe. They suggest those red rocks which are often associated with basic rocks, apparently, as the result of chemical splitting in the original molten magma, such as Grant's augite granites,* some of the diorite porphyrites of Picnic Rocks near Presque Isle, etc. But in other places the acid rock seems more independent.

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*So I am informed by Godfrey Vaudrey, who worked in the mine from 1880 on, and now spends his summers on the island, fishing.

The mining began in an old Indian pit which was on a vein that crossed the bluff. From 1 foot the vein widened to 3 feet, when they had sunk 35 to 40 feet, and it contained a good deal of copper—a sheet 3 to 4 inches thick in the middle of the vein.

Beside the above explorations we find on the north side of the bluff a number of others, working along the lower contact of the trap or in the softer underlying amygdaloidal beds. Some of these are very laumonitic, unpromising, broken stuff, but expose a contact and furnish a good opportunity to determine its dip and strike. Strike N. 65° E., dip to S. E. 20°. Another strike observation is N. 55° E. The contact lies only about 30 feet or so below the crest of the ridge, which is about 150 feet high.

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*Minn. Geol. Survey, 21st Ann. Rep't, 1894, Pt. II.

The vein above mentioned is probably parallel to a set of prominent joints; strike N. 40° E., dip to N. W. 70°.

The western part of the Minong territory has not been developed, though I have heard that offers were made for it on tribute. The sketch map, Fig. 1, has no pretensions to accuracy, as I have not been able to get any trace of a mine map, but will serve to illustrate the general relations.

But little later than the Minong Mine, and earlier in organization and in running its course, was the Island Mine. The Island Copper Mining Company was formed in 1873 to exploit a copper-bearing conglomerate, which had been dicovered under S. W. Hill the year before, near the head of Siskowit bay, close to the north quarter-post of Sec. 29, T. 64, R. 37. Prominent in its organization were Messrs. Hardy, Devereaux, F. White, Mason and S. W. Hill. Murdoch was mining engineer, Hardy was agent. Two shafts were sunk, respectively 200 feet and 150 feet deep and 350 feet apart, which were connected on two levels, and a third shaft 350 feet farther west is down 50 feet.* In 1875 a stamp mill was built, but burned down almost immediately. The discouraged company leased the mine to the Equal Rights Tribute Company, of which S. E. Cleaves was a prominent stockholder. The name was later changed to the Island Tribute Company, and E. Vivian, now engineer at Calumet, was in charge. The last season of work was in 1877. When Winchell was there in 1879, things were still in good condition, including the courthouse, for this was once the county seat of Isle Royale county. Now the location is pretty well devastated.

The shafts of the Island Mine are in a conglomerate from 14 to 16 feet thick. The two feet near the foot wall, I am informed, were the rich part. At any rate, while very rich blocks of rock may be found, not the whole thickness of the conglomerate shows copper, by any means. Specimens 14746-14749 illustrate the bed and its foot and hanging. The outcrop is about 230 steps south of the north quarter-post, the east shaft dipping 19°, while the west one dipped 25°. Immediately to the south there is a rise of land with exposures of mottled melaphyres, while to the north the grade is steadily up hill over amygdaloids and beds with agates, of a more acid "ashbed" type. Various facts lead me to identify this conglomerate with bed No. 35 of Marvine's Eagle River section.* It appears to be the first normal conglomerate, with a considerable variety in pebbles, and a generally quartzose or sandy character, that one notices in coming up above the greenstone in each section.

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*Swineford, p. 12.

The only other mine that we have to mention that was active during this period, is the Saginaw Mine, on Sec. 35, T. 66, R. 34, near where the Ohio and Isle Royale had worked so many years before. Tim. Nester, of Marquette, was the agent. They began work in 1875, and closed in 1878 or 1879. Their ore was the same as that of the Ohio and Isle Royale, copper finely disseminated in epidote, and hard to stamp. The production of the last three mines above mentioned was:

	Minong.		Island.		Saginaw.	
	Tons.	Pounds.	Tons.	Pounds.	Tons.	Pounds.
1875	24	344				
1876	57	537	24	340		
1877	52	892	44	867	0	1,800
1878	45	596				
1879	36	515			24	1,464
1880	13	1.407				
1881	7	1,397				
1882	10	1,380				
1883	1	1,582				

§ 4. Recent explorations, 1889-1896.

With the closing of the Minong Mine in 1883, the island sank into rest once more. The period of activity was somewhat longer than the preceding period of activity, and the period of repose following very much shorter than the preceding period of repose.

In 1889 the Isle Royale Land Corporation, having much of the estate of the North American Mineral Land Corporation, and adding some smaller areas to it, began work once more. Their estate amounted to some 84,000 acres, and the stock was largely held in England, where, also, the office was, although Jacob Houghton, of Detroit, was one of the largest individual stockholders, and the Consulting Engineer as well; Mr. J. H. Thompson was First President, i. e., Chairman; after him G. H. Feldtmann was Chairman; Leslie was Secretary, succeeded by Alex. H. Hay; W. W. Stockly was Engineer, to whom much of the value of this report is due; and S. S. Robinson, Manager.

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*Geol. Surv. of Mich., Vol. I, Pt. II, p. 124. For a full discussion see below, Chapter III, §3.

Work was begun in June, 1889 (Report Com. Min. Stat. for 1889, p. 26). It consisted merely in trenching and costeaning until August, 1890. Work was first begun in the neighborhood of Todd harbor, around what was known as Haytown, on Sec. 11, T. 65, R. 36, and also on the north flank of the Greenstone range, on Sec. 13 and Sec. 12, T. 65, R. 36, and on Sec. 7, T. 65, R. 35 (Pl. XI). Work was also begun about Washington harbor, which was made headquarters of the company, "Ghyllbank," S. 29, T. 64, R. 38. In August, 1890, an auxiliary company, the Wendigo Copper Company, was formed, to which some of the lands around the head of Washington harbor were assigned (Pl. II). This company began a systematic series of diamond drill holes, which gave a practically continuous section across T. 64, R. 38 (I-K, Pl. XIII). Their other tunnels and explorations were not fortunate, and in 1892 almost all work was suspended, though a small party was left to finish drilling two holes on the extreme northwest of the section, close to the water's edge. It was the extreme and unique value of the geological column afforded by these drill cores, which promised to be the key, not merely to the geology of the island, but perhaps to the stratigraphy of the Keweenaw series in general, and even to throw light also on broader questions of the successions of eruptive rocks,—questions of world-wide significance,—which caused the State Geologist to feel that this material must be saved to science at any cost, even though it delayed publication in other directions. Moreover, this cross-section was the last thing finished of the explorations, so that none of the ground shown up by it has been farther tested. It was thus of the highest importance for the future explorations that the record and results of these explorations should be saved. Therefore I spent the time between August 4 and November 10, of 1893, with Chas. LeSage, boatman, and W. W. Stockly, the Engineer of the Wendigo Copper Company, in going over the drill cores, some 9,000 feet, taking notes and samples, and in visiting and taking notes of the explorations in other parts of the island. At that time the secretary of the company, Mr. Hay, was there, and the Isle Royale Land Corporation has kept and is still keeping some one in charge of the property, so that the diamond drills are still there in good order, ready to renew work. The company has also had other plans for the development of the island as a summer resort, and for the exploration of its timber. There are a large number of fishermen that set their nets around the island every summer, and the steamer Hiram R. Dixon stops at the island during the summer season, on her way from Port Arthur to Duluth. The island is also frequently resorted to by camping parties from Duluth, and John F. Johns lets a cottage on an island north of Washington Island to such parties, or they camp in tents or in the deserted lighthouse at Rock harbor and at other points. The picturesque beauty of the island is only faintly indicated by some of the illustrations of this report (Plates VIII, IX, X, XIV, taken from negatives made by Mr. Stockly), and every one who has been there has sung its praises. The scenery is of that fiord type of scenery, which lends such a charm to the coasts of Maine and Norway, and is not unworthy of comparison with them. It is not surprising, therefore, that the company aforesaid planned to make a summer resort on the island. Rock harbor was the place they had fixed on, and a town site has been surveyed, on Sec. 23, T. 66, R. 34, close to the location of the erstwhile Ransom.

Between September 16 and October 12, 1895, I revisited the island with R. T. Mason, assistant, D. C. Forbes and G. Wallace, partly to get farther barometric data, and partly to examine more carefully the region between Rock harbor and Siskowit bay. In the meantime no work had been done there by miners.

The history of these latest explorations (I trust it is not yet finished), must be gathered from the local papers and from private data. Further accounts of these explorations are given in various places in this report, for I have not attempted to summarize them in this historical chapter. The special Regatta Edition of the Duluth Evening Herald in July, 1890, contained under the heads "Lotus Land of the Lake," p. 7, and "A Western Mecca," p. 10, some accounts of the plans of the Isle Royale Land Corporation and its auxiliary companies. In the summer of 1896, Mr. Jacob Houghton continued explorations on the vein running near drill-hole No. 4 or No. 5, but these explorations were suddenly brought to an end by the failure of a Duluth bank.

A word, in closing, on those maps of the island which appear to have incorporated original observations.

The first map of which I know, is that of the Jesuit missionaries in 1670-1671, reprinted by Foster and Whitney.

In 1825 there was a chart of the Canadian shore prepared for the British Admiralty by Capt. Bayfield, which included a delineation of Isle Royale and soundings around it, which were used on Foster and Whitney's map.

Then in Executive Document No. 5, accompanying the Annual Message to the 31st Congress, 1849, there are two maps:

The first, by C. T. Jackson, United States Geologist, shows the locations of the veins, and of the various explorations, and gives the swamps in detail, but is not as accurate in its delineation of the sandstone conglomerate at the southwest point of the island, as the other.

The second was prepared by J. W. Foster and J. D. Whitney, with the assitance of S. W. Hill and S. W. Chlatter (*Sic!* Schlatter). One or two locations are given on this map that are not given on Jackson's, and the sedimentaries are more fully indicated. It is the best geological map of Isle Royale heretofore published.

In their final report, Pt. II, in 1851, Pt. I having been printed the previous year (Senate Special Session, March, 1851, Executive Document, No. 4) was included a general geological map of the Lake Superior Land District, with a small map of Isle Royale. This adds nothing to the large map before mentioned, and is less accurate than that in bringing the conglomerate at the southwest end of the island still farther to the south.

In 1864 was published what is known as the Hulbert map, compiled and drawn by J. C. Booth and E. J. Hulbert, with geological notes from Foster and Whitney, S. W. Hill, W. H. Stevens, N. (*sic!* H. F. Quarre?) d'Aligny and Ed. J. Hulbert. The conglomerate band from Siskowit bay to Rainbow cove is too far south, as on Foster and Whitney's small map, and probably unintentionally the region south of it is colored trap instead of sandstone.

In 1871 S. W. Hill published a map very different from any that had preceded it. The south boundary of the trap range is brought north again to where it was given by Jackson, and a belt sketched nearly parallel to it, running from Scovill point to Huginnin cove, which does not correspond to any geological feature that I have observed. There are a large number of veins noted. If we knew on just what data these were drawn in, and how far they represented the results of Hill's extensive explorations, they might have much more value. But as the map was issued in 1871, the year his explorations began, it has probably more the character of a prospectus.

In 1871 the U. S. lake survey chart of Isle Royale, with detail charts of the more important harbors, was published. The scale of the principal map is 1:120,000. This is beautifully engraved and covers all but a small part of the interior of the island. Much of the island was contoured, and these contours have been the base of the contour map of the island now being issued by the United States Geological Survey.

In 1892, Mr. Stockley compiled a map, using U. S. Linear Survey notes for section lines, township plats of the Land Office for shore lines, and original surveys; this map has had a considerable circulation in blueprint form, and was the base used in our geological researches.

Mr. Stockly, however, discovered that these plats had not been made from a careful platting of the original Government field notes, and consequently he undertook the task of computing the whole matter over again, a herculean task, when one considers the amount of meandering there is in the island. The resultant map is the base used for this report, and we may fairly boast of having the most accurate map hitherto published. The original Land Office notes by Ives have been supplemented so far as needful, from our geological note books, Mr. Stockly's surveys, and the Lake Survey chart. But it should be said that Mr. Ives and his assistants did work of a much higher character than has often been done since his time for the Linear Survey. The errors of closings are small, the work having been done with the solar compass, and magnetic variations, rock-ridges, etc., are carefully and frequently noted. In this brief resumé, only those maps have been noted which are supposed to have incorporated original material, and this rules out such maps as that of Irving, in "Copper-bearing Rocks of Lake Superior" (Pl. XXVII), because none of his parties visited the island.

CHAPTER II

CONSTRUCTION OF CROSS SECTION FROM DRILL RECORDS

§ 1. Deviation of drill holes.

Before we proceed to give an account of the succession of rocks revealed by the Wendigo Company's borings, I have thought it well to give some account of the method of construction of a cross-section. The use of the diamond drill is comparatively new, and but little can yet be found in the literature upon the method of treating such records as the drill may give, and of avoiding the errors to which one is liable in constructing a section from them. This chapter may therefore serve a double purpose,—as a credential for our work, and as a guide to others who have similar work.

In our work we have had to assume that the drill holes were straight, and with one exception vertical, as they were intended to be. This is a good deal of an assumption, for a diamond drill is in this respect very different from a churn drill, where any considerable deviation from the vertical is sure to make trouble. In the diamond drill the drill is being pressed and not dropped into the earth, and however stiff a few feet of the rods by which it is pressed may seem, the discussion at the second annual meeting of the Lake Superior Mining Institute, March, 1894,* showed plainly that they would easily bend as much as 6 feet in 50 feet and the experiments of Mr. Channing, there recorded, show that his inclined holes went very much astray. By using a tube with 20% of hydrofluoric acid to etch the glass, he measured the dip of his holes at various depths.

"The final method of work was as follows: A blank tube was put in the combined bit and core shell from the top end until the lower end rested on the spring. Holding this in position it was laid beside the core barrel so that the length of thread was allowed for, and a file mark made on the barrel core just even with the top of the glass stopper. A dry wooden plug was made to fit the core barrel and driven in until it just cleared a point corresponding to the file mark. The core barrel was now clamped in a vise in a nearly vertical position.

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* Vol. II, pp 23 32.

"The stopper of the tube was held in a tin spoon with a little paraffine over a candle flame and the upper end of the tube warmed. An inch of 20% hydrofluoric acid was carefully poured in the tube, then an inch of water and the stopper taken from the melted spoon of wax, smartly rapped to throw off any excess of paraffine and quickly put in the tube. The acid immediately heated up the tube but no ill effects were felt from this. Wrapping a thread or two of lamp wicking around the neck of the tube, it was put in the core shell and still holding it in an upright position the upper end was introduced into the core barrel and the thread between the shell and the barrel screwed up. Carrying the barrel in an upright position it was put down the hole and no special pains taken in lowering the rods, save to touch the bottom of the hole carefully."

His results were roughly as follows:

Hole No.	1	2	3	4	5	6	7	8	9
Deviation in degrees per hundred feet	4°	5°	3°	12°	12°	8°	8°	8°	4°

The cause of this deviation he attributes to the weight of the core barrel in a slightly larger hole inclining the drill upward.

So far as this cause is concerned, we see that it will not operate so much in a vertical hole. Moreover, in a vertical hole there is no reason to suppose that the deviation will be constantly in one direction, and if the deviation is at random, the drill hole will describe an irregular spiral, and such cases have been known. For instance, Mr. W. W. Stockly reports a case where a shaft 8 feet square, in following a vertical drill hole, found it describing a spiral, and at 500 feet depth it had shifted from the center to the corner of the shaft, and then disappeared for good. We shall need to correct our measurements by multiplying them by the cosine of the angle which the hole makes with the vertical. As long as the deviation from the vertical does not exceed 8°, the consequent correction will not be more than 1 per cent. It is not probable, therefore, that in assuming our drill holes vertical we make any considerable error. This is also shown by the way our results check up.

§ 2. Determination of dip and of true thickness of bed.

A certain amount of the softer rock is ground away, but in general the drill cores show us pretty well the vertical width of the several beds along the drill holes. Now, beside this, we must also know the dip, to get the true thickness of the bed. We have the following methods of obtaining the dip:

(1) By the lines of bedding or of flow, which we often observe running across the drill core. Thus, holding the drills vertical, we can measure the dip directly from these lines. Of course, we cannot discriminate small irregularities or cross-bedding in this way.

(2) By field observations of the dip on adjacent outcrops. Unfortunately we have seen no outcrops of sediments close to the drill holes. Observations of contacts of flows are important, but observations based merely on the attitude of the joints of a rock can not be trusted for precise results, though the columnar jointing more or less at right angles to the surface of cooling, and a parting about parallel to the same surface, often give a clear idea of the general dip.

(3) By comparison of the depths at which some bed, so characteristic as to be surely identified, is found in different holes. The strike of the rocks and the relative altitudes of the drill holes being known, this is much the more accurate way of determining the dip, and also enables us with great certainty to piece on to the record of one hole that of another. It requires the drill holes to be near enough or deep enough to overlap. This, unfortunately, is only twice the case in the Isle Royale drill cores, to such an extent that we can identify corresponding beds with absolute certainty. It is a penny-wise pound-foolish policy to let the drill holes only barely overlap, for the sake of saving the cost of a few extra feet, when thereby the uncertainty of the whole section is greatly increased, when, too, the proving of the same bed at diferent points is of interest.

It is obvious that this method of overlap gives us what may be called the average dip between the drill holes, which might be slightly different from the dip at any one drill hole, and if the strike were so different at the two drill holes that it was not permissible to use an average strike, the problem would be much more complex, and new factors would be introduced. Assuming dip and strike as constant between two holes, we have the following simple reckoning. In Fig. 2 let A be the position of the bed in drill hole No. 1 and D the position of the same bed in drill hole No. 2. Let DE be a horizontal line parallel to the strike of the bed. All points of DE will then lie in the bed and be at the same time in a horizontal plane. Let AC be a line perpendicular to DE at C through A. It will also lie in the bed and be the direction of dip, since it is perpendicular to the strike. Let B be directly below A on the same level as C and D. Then the tan of the dip, which is $\angle$ ABC, $=$ AB : BC. But AB is equal to the difference in level of A and D. Moreover BC$=$BD. sin $\angle$ CDB. This angle $\angle$ CDB is the difference of the direction of the strike and of the direction of drill hole No. 1 from drill hole No. 2.

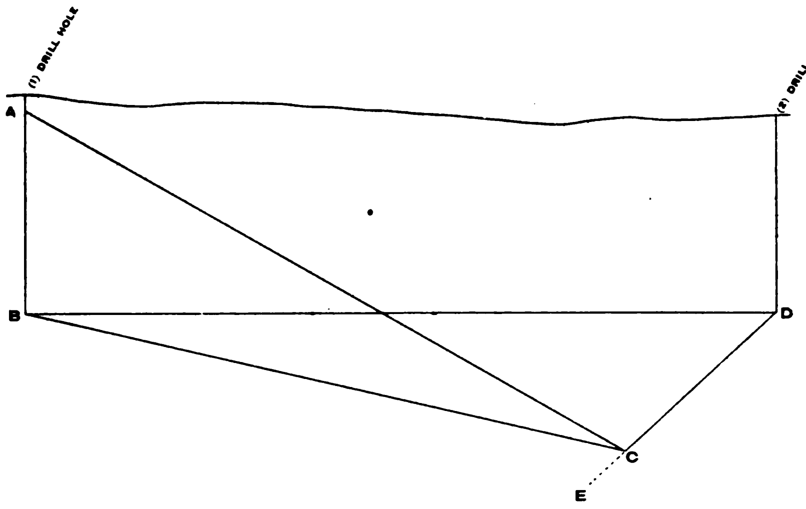

Fig. 2

Illustrates the computation of the dip from observations upon the same bed, at A in drill hole (1) and at D in drill hole (2).

Thus if a^1 be the altitude of the top of drill hole No. 1, and
a^2 be the altitude of the top of drill hole No. 2, and
d^1 be the depth of the bed in drill hole No. 1, and
d^2 be the depth of the bed in drill hole No. 2, and if
s be the strike, and b the bearing of hole No. 1 from hole No. 2, and the distance between the two holes, i. e., BD, be 1, then tan

$$\text{dip} = \frac{AB}{BC} = \frac{(a^1 - d^1) - (a^2 - d^2)}{\text{l. sin } (s-b)} = \frac{(a^1 - a^2) - (d^1 - d^2)}{\text{l. sin } (s - b)} = \frac{(d^2 - d^1) + (a^1 - a^2)}{\text{l. sin } (s - b)}$$

If the bearing of drill hole No. 1 is nearly at right angles to the strike, so that (s--b) is near 90°, but the dip is not great, an error in estimating the strike will not produce nearly as great an error in the dip. Such is practically the case before us. Moreover, if we take the distance apart of the drill holes, from their projection on a cross-section perpendicular to the strike we at once obtain the denominator l. sin (s--b). There is another more serious error liable to be encountered, in that a fault may have intervened so that the bed ACD will not be continuous. This is certainly a serious feature of this method of determining the dip. It can be guarded against only by watching to see if either set of drill cores show signs of such a fault, by examination of the surroundings to see if such a fault be geologically likely, and by checking up the results by other methods. A modification of the third method consists in connecting the outcrop of a bed with its position in the drill hole. In such case the outcrop may be considered as though it were at 0 feet depth in another drill hole.

(4) The fourth method of finding the correction for dip is hardly a method by itself, but consists in certain general considerations of analogy and structure, which may serve as a check upon the previous methods. Thus we may argue from the analogy of the Keweenawan series elsewhere that the dip should flatten in going toward the top of the series.

§ 3. Combination of records of different holes.

Having corrected the beds in each drill hole from their vertical width along the drill hole to their true thickness, the next step is to combine the records.

(1) If the drill holes overlap, so that each cuts the same bed or beds, and these are so distinct that we can recognize the same bed in the two holes, then when in constructing our geological column we come to this bed, we can pass from the one hole to the other and continue the record.

(2) If we cannot be sure which are corresponding beds, or if the holes do not overlap, then we can find to what point in that drill hole which is the higher in the series, or in the hypothetical downward continuation of that hole the top of the other drill hole does correspond,—provided we have found the dip in some other way,—by using the formula on page 31 and merely working the problem (3) backward. For in this case placing $d^1 = 0$, we may rewrite the formula given on page 30 in a form from which to find d^2; thus $\tan (\text{dip})\ l. \sin (s - b) - (a^1 - a^2) = d^2$. This method should also be used as a check on others. But here, as before, faults may cause us serious error.

§ 4. Effects of faults.

Faults going across the strike are in general steep on Isle Royale, and we shall be warned of their probable existence, if they cut the drill hole, by considerable streaks of vein rock. Faults running with the strike would be much more readily confused with the contact of the two flows, especially if they follow the same as they often do. Let us then consider what the effect on our record would be, of the various classes of faults.

In the first place we can see that a simple slide like the Allouez slide (at Eagle River gap, Keweenaw Point) exactly accordant with the dip and strike, will not disturb the record at all. Faults with a dip flatter than the dip of the beds, and the upper side sliding down, are not likely to occur. Now, for simplicity's sake, suppose our series of beds to dip southerly, as, in fact, they do, and let us first consider faults that practically coincide with the strike of the formation. We lose no generality in assuming that the beds dip south, if we give the faults all possible directions, and the assumption will shorten our expressions. Now, in strike-faults we shall consider first:

A. The south side thrown down. Fig. 3.

If we estimate the dip from a bed in hole No. 2 below the fault, and in hole No. 1 above it, we shall err in making the dip too steep. If we have obtained the dip in some other way, then suppose,—

(1) Hade of fault either way, north or south; fault between two holes, cutting neither. In this case, Fig. 3, we may under-estimate or ignore the gap between them, or, if they ought, according to the distance and gap between them, to overlap, we shall find at depths at which certain beds should correspond, beds which did not correspond, and if we could force them into correspondence, assuming for example that bed A of hole No. 1 was equivalent to bed D of hole No. 2, instead of bed C, we should make our geological column shorter than it ought to be.

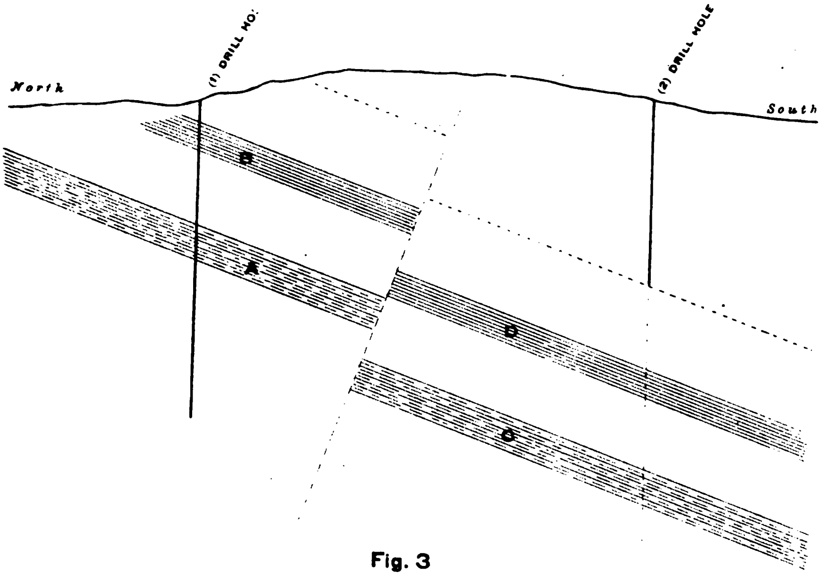

Fig. 3

Illustrates the effect of a fault hading north, which throws the south side down and cuts neither drill hole.

(2) Hade of fault to north, and the south hole (No. 2) passing through from above the fault to below it, Fig. 4. There will be a repetition of beds in the neighborhood of the fault. We shall be in danger of supposing in case, for example, hole No. 2 stops at bed D, that they fill a part of the column occupied by a gap really unknown. If the holes are so near that without a fault they would

overlap, we shall find that the lower part of hole No. 2 does not correspond to No. 1, as we should expect, and thus probably be warned of the fault. Finally, by correlating C with F we might possibly be led to imagine too steep a dip.

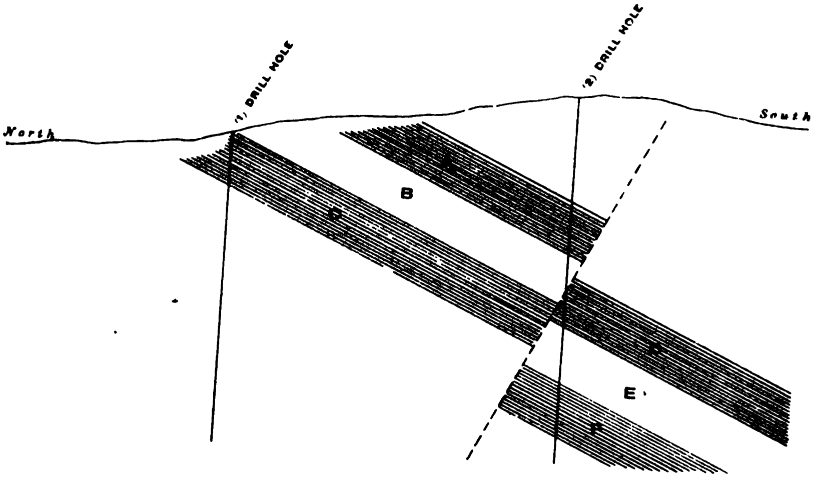

Fig. 4

Illustrates the effect of a fault hading north, which throws the south side down and cuts the south drill hole.

(3) Hade of fault to north, as before, but the north hole (No. 1) is cut by the fault. The effect, so far as correlation is concerned, will in general practically be the same as when the north hole does not go down far enough to reach the fault, case (1), since we should naturally use the top of the north hole (No. 1) to correlate with the bottom of the south hole (No. 2). Below the line of the fault, correlations could be made directly with the south hole, and in the record of the north hole there would be a reduplication of beds.

(4) Hade to south, and north hole cut by fault. There will be no extra difficulty in correlating the beds. The record of the north hole (No. 1) will be deficient by some beds, as is obvious from Fig. 5, unless indeed the fault is one with a very flat dip; flatter than that of the beds, in which case it would be likely to cut both holes.

But such flat faults are not known except as over-thrusts as previously noted. Such a fault would cause reduplication of beds in the record of (1).

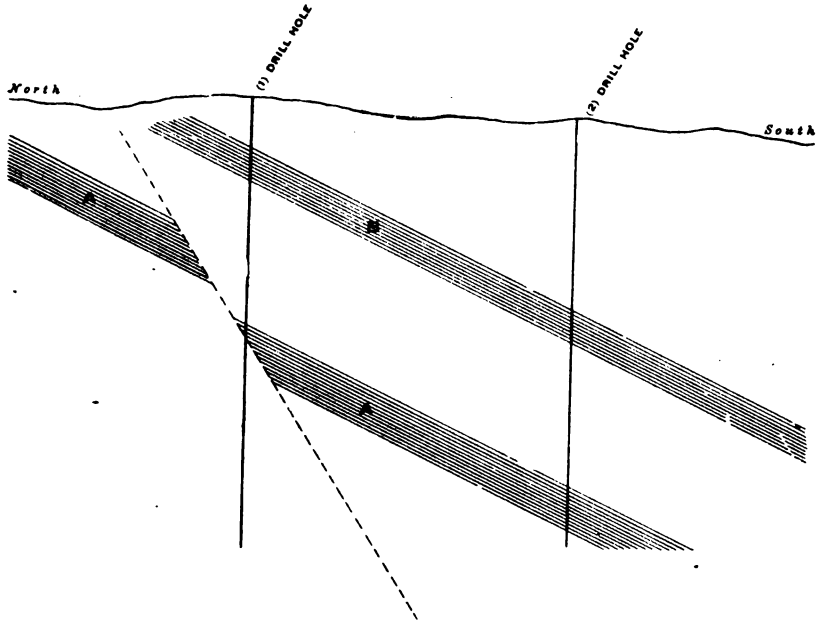

Fig. 5

Illustrates the effect of a fault hading south, which throws the south side down and cuts the north drill hole.

(5) Hade to south, and south hole cut by fault; dip of beds flatter than dip of fault. Fig. 6.

If the north hole is near enough to overlap the bottom of the south hole, true correspondences and dips can be obtained by matching the beds, from the bottom of the south hole up to the fault, i. e., to D, in Fig. 6.

Then there will be a loss of certain beds. If the north hole also contains a bed which can be recognized in the upper part of the south hole, e. g., the bed B, the missing beds will be found in the record of the former; the dip computed from the two occurrences of the bed B will be too steep and the fault will be detected. Compare the correlation of drill holes IX and VIII, in chapter III. In this case (5) there is danger of establishing a false correspondence, for suppose that B and A, Fig. 6, of the south hole are assumed to correspond with B and A of the north hole, when really they are equivalent to B′ and A′, which were not cut by the north hole, while the real A and B have been cut out by the fault. In this case, or if we could not match any beds above the fault, and yet were not aware of the discordance, because the north hole was so far away that its highest bed would come below the fault in the south hole, we might leave beds out of our series unawares.

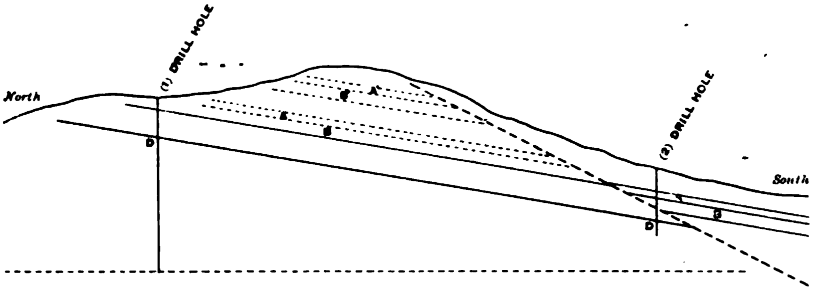

Fig. 6

Illustrates the effect of a fault hading south, which throws the south side down and cuts the south drill hole.

If, then, the holes are so deep and so near together that normally the beds cut by them should overlap somewhat, one case may occur where there is great liability to error,—that is when, with no duplication nor correspondence of beds to warn us, the hade of the fault is to the south and the south hole is cut by the fault so high up as to be out of the way of the matches with the north hole.

B. The south side thrown up; dip of fault if to south, steeper than dip of beds.

(1) If neither hole is cut by the fault, Fig. 7, if we estimate the dip of beds from the holes, we shall make it too flat, or possibly even find it the wrong way. If we get our dip in some other way, we shall be in danger of getting our column too thick by repetition of beds. If then we find the bottom bed B of the south hole (No. 2)

match the top bed A of the north hole (No. 1), we shall see if the dip thus derived (by method (3) on p. 63), agrees with what we should otherwise expect. If it is abnormally flat, we may suspect a fault of this class.

(2) If the north hole is cut by the fault with a south hade, we are not so likely to err in dip or correlation, but there will be a reduplication of the record in that hole, which may again lead us to to get our column too thick.

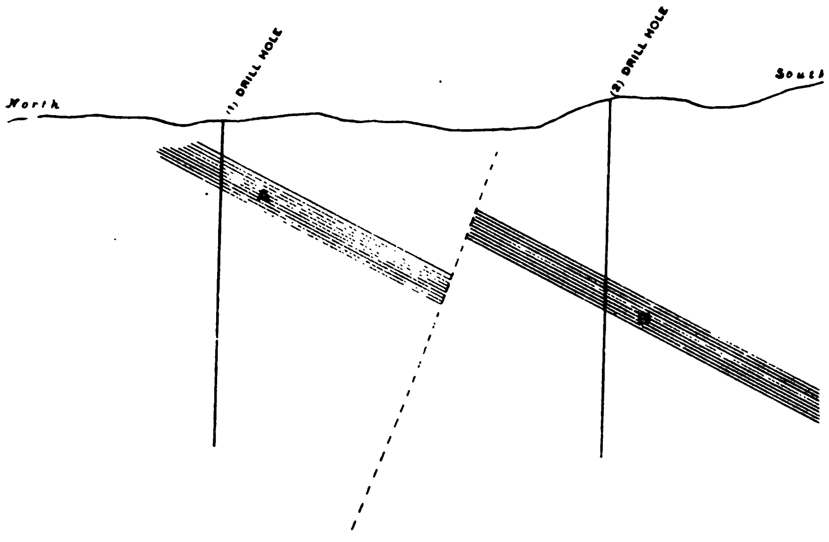

Fig. 7

Illustrates the effect of a fault hading north, which throws the south side up and cuts neither drill hole.

(3) If the south hole is cut by the fault with a south hade, we shall have a reduplication of record as before, and while the correlations, below the fault, of the top of the north with the bottom of the south hole will be all right, those above will give dips too flat.

(4) If the north hole is cut by the fault with a north hade, we have the case shown in Fig. 8, between holes No. 2 and No. 3. This is an especially important case to discuss, as Lawson has suggested that it occurs frequently on the north shore of Lake Superior adjacent to

Isle Royale.* In a case of this kind we shall be unable to correlate the top of the north hole, No. 2, with the bottom of the south hole, No. 3, correctly, and shall be likely to make our geological column too thick, by reduplication of beds. The means of detecting this kind of fault will be by the recurrence of the same beds. For example, the set of beds A will occur again at a higher level south of the fault. Of course, if the throw is very great, they may occur at a considerable distance south beyond the hole next south of the fault, and be found only in some higher hole. We shall have to look over our records to see if there is any such recurrence in the succession of beds as to warrant the idea of such faults.

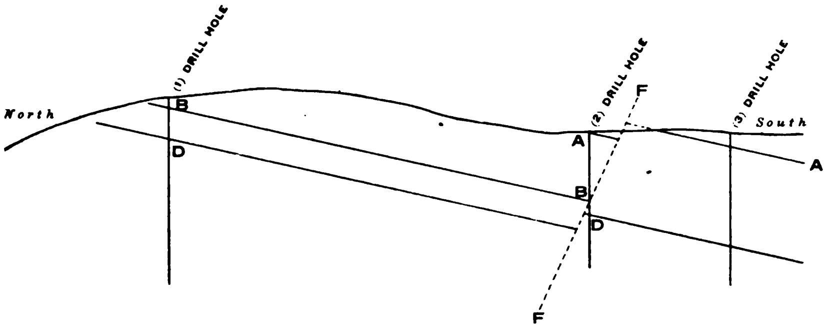

Fig. 8

Illustrates the effect of a fault hading north, which throws the south side up and cuts either drill hole.

(5) If it is the south hole which is cut by the fault with a north hade, Fig. 8, holes No. 1 and No. 2, the difficulties and dangers will be much as in the preceding case. If the holes are so near together that there is an overlap above the fault, then the correlation can be there correctly made, while beds below the fault will give dips too flat.

In any and all of the above cases, if the fault cuts both holes, the relations of the parts of the holes that are on the same side of the fault will be normal, and of the parts on opposite sides of the fault abnormal, following the appropriate cases above. In such cases, inasmuch as the hade of the fault is steeper than the dip, the holes must be quite near each other, and with south-hading faults there will almost certainly be at least two corresponding beds, and there should be no difficulty in noticing the fault, unless the beds are extremely uniform and similar. In the north-hading faults, at the bottom of the north hole, we ought to find a bed that will correspond to one in appropriate position in the south hole, while the lack of correspondence in the upper part of the hole would tell the story of the faulting.

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*20th Annual Report, State Geologist, Minn. p. 192; also Bulletin No. 8, of same survey, pp. 33, 39, 45.

There remains to consider:

C. Hade of fault flatter than dip of beds. In this case, as we have said, it is almost invariable that the throw is up, as it is hard to conceive the mechanics that would lead to a down throw on a plane flatter than the dip. But reverse faults, so-called thrust planes, are more to be expected.

(1) Neither hole cut. This would not happen if the holes were planned to overlap at the normal dip, when undisturbed, and hence is an unimportant case. There will be no possibility of correlating correctly.

(a) If the south side is thrown up,—thrust,—the gap in the column will be greater than supposed. The geological column will be made too short.

(b) If the south side has slid down, the gap in the record will be less than supposed. The column will be made too long.

(2) If the south hole alone is cut, below the fault line it may correspond to the north hole. At the fault line,—

(a) If the south side is thrown up,—thrust,—there will be a gap in the geological column unsuspected, at the fault, and the geological column will be made too short.

(b) If the south side has slid down there will be a repetition in the series, and the geological column will be made too long.

(3) North hole cut. In this case the south hole also must be cut, if they are near enough to correspond. Below the fault the two holes may correspond and be correlated, and a correct dip be derived.

There may also be a correlation above the fault line. The series between will not correspond.

(a) If the south side is thrown up, there will be a gap of unknown size in the column, possibly two. We may or may not be able to piece out the record from the four parts of the column given.

(b) If the south side has slid down, there will be a reduplication in the series and we ought to be able to detect the fault and correct the series, if the beds are sufficiently characteristic. It will be noticed that, in a series of drill holes planned to overlap, all faults will tend to produce repetitions of the beds, if the hade is to the north or the direction of downthrow is to the north, except in the case of flat overthrust faults. If corresponding beds can be noted, the abnormal dips that would be derived from them generally give a clue to faults. The only faults that cannot be thus detected, if the holes are properly spaced and there is enough variety in the beds to admit of correlations, are—a normal fault with dip south, greater than that of the beds;—a reverse fault with dip south, less than that of the beds.

In regard to faults that do not coincide in strike with the beds, we need consider only that component of the motion which is up or down, and the angle at which the faults cut the plane of dip, and having found their projection on the cross-section, we shall find that the same rules apply as above, since the drill holes give us information only concerning the vertical position, and will be not at all concerned with the displacement in other directions. We may also look at it in another way. In our cross-section the boundary between that part of the beds which we consider undisturbed by the fault, and that part which we consider moved by it, will be given by the projection of the plane of the fault on the plane of the dip, and the motion of the disturbed part, which is of course parallel to the plane of the fault, may be resolved into two parts, the one along the line of projection and the other horizontal in the direction of the strike, which we need not consider.

In order fully to grasp this case we shall need to use some projection like the stereographic, which I have used for other purposes, and of which a description will be found in Dana's larger mineralogy and also in Bull. Geol. Soc. Am., Vol. II., pp. 365, 368, Pl. 14. We will apply this particularly to the discussion of two classes of faults, which we know occur on Isle Royale, and may be expected to occur in our cross-section. The first class is well exemplified at the entrance to Chippewa Harbor. These faults are parallel to joints running nearly east and west, more so, at all events, than the strike, and they dip at about 70° to the north. The second class occurs at various points, and fault the Minong trap. One probably comes out near Huginnin Cove. Another lies evidently between drill holes No. XV and No. XVI, which are both close to the northwest shore of the island, throwing No. XV, which is northeast of No. XVI, up about fifty feet, and apparently throwing the outcrop to the right or southeast in going northeast. This throw can be seen 25 chains, *i. e.*, 1650 feet, west of the southeast corner of Sec. 19, T. 64, R. 38, and about 500 steps west and 200 steps north of the southeast corner of Sec. 16, T. 64, R. 38.

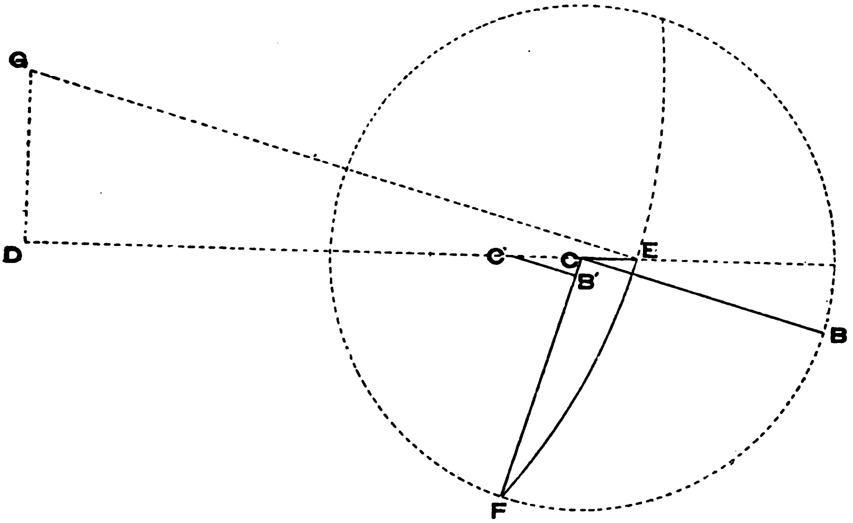


Fig. 9.

Illustrates by a stereographic projection the displacement of the bed C^1B^1CB by a fault, CEF, of the Chippewa Harbor type.

Let us study to what classes these faults respectively belong, and what effects they would produce. Figure 9 illustrates the Chippewa Harbor type in stereographic projection. To understand it we must imagine ourselves at the horizontal level looking northeasterly in the direction of the strike of the formation, so that a line representing that strike would be foreshortened to mere point at C. Then the dotted circle represents an arc passing through the zenith, and the area within it represents half the universe, and any direction at right angles to the strike will be represented by a radius of that circle r; thus CB may represent the dip of the beds. Any direction not perpendicular to the strike will be foreshortened more or less. Thus CE may represent the direction east, which we will also take as the direction of the strike of the faults. According to the principles of the stereographic projection, then, $\frac{CE}{r}$ is equal to the tangent of half the angle between the strike of the beds and the strike of the fault, which is in the present case about 25°. The angle ECB is, of course, equal to the dip of the beds. To get the dip of the fault in the direction of the dip of the beds, we draw EG, making an angle with the horizontal EC equal to the overhang or hade (the complement of the dip) of the fault. This angle is taken on that side of E toward which the fault dips. Then we also take on the opposite side of C from E a distance CD, equal to the cotangent of the difference in strike of fault and beds—in the case of the Chippewa Harbor fault about 25°—and erect a vertical which cuts the line EG at G. Then G thus found will be the centre of a circle EF, which will cut the dotted circle "primitive" at F. Then by the theory of the stereographic projection, CF will be where the fault will cut the plane of dip, which is the plane of projection, and CEF will represent the fault plane.

Going along the strike of the beds to the northeast, at Chippewa Harbor, we find the outcrop thrown to the left as at C′; thus to the north of the fault the bed CB will be displaced to C′B′. We see then that the fault belongs to the class B 4, with downthrow and hade to the north, and is a normal fault. *It will be noticed too that CF is nearly perpendicular to CB, as if the fault had been influenced somewhat by joints perpendicular to the bedding, which are common in all formations, but especially in igneous rocks.*

Turning now to the second class, represented in Fig. 10, we find the strike of the faults near north, generally a trifle east of north. Then the strike of the beds being foreshortened to the point

C as before, inasmuch as the strike of the beds is near N. 55° E., the strike of the faults will lie to the left and will be represented by the line CN foreshortened somewhat, and proportional to tangent ½ 55° This class of faults is very nearly vertical, sometimes dipping a little to the east, sometimes a little to the west. Of course if such a fault were exactly vertical, a vertical drill hole once in it would never get out of it. Such a fault occurring between two drill holes would produce the same effect whether it had a slight hade one way or the other. We will assume for our drawing a slight hade to the west which is perhaps the more common. Then, just as before, we

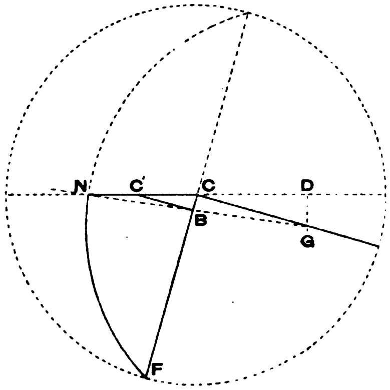


Fig. 10

Illustrates by a stereographic projection the displacement of the bed CG-C^1B by a fault, NCF, of the Huginnin type.

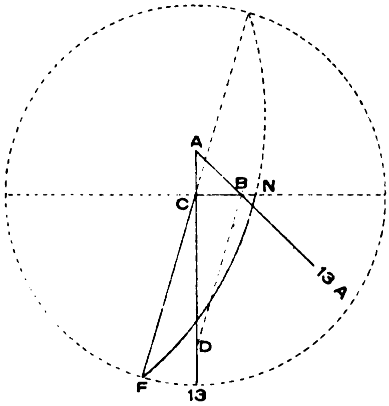


Fig. 11

Illustrates by a stereographic projection the displacement of the fault at drill hole No. XIII.

lay off CD equal to cot 55°, find G, the intersection of the perpendicular at D with a line making an angle with the horizontal equal to the overhang or hade, and about G describe the circle NF. NFC once more represents the fault plane. Going northeast along the strike, that is, in the direction of C, we find the outcrop thrown to the right. Thus, crossing the fault plane NCF we find C′ thrown to C. Thus the east side of the fault is thrown up and the west side down. Thus we see that these field observations on the outcrops harmonize perfectly with what the records of holes Nos. XV and XVI show us. This class of faults, though so different in strike, would then be of the same group as the Chippewa Harbor, northward-hading normal faults, the fault-plane being nearly perpendicular to the plane of dip.

In Chap. III, at the beginning of the description of drill hole No. XIII, there is further study of a fault of this class, which probably affects this drill hole and XIIIA.

§ 5. Description of records and drill holes.

At the bottom of our record we have three drill holes all close to the northwest shore of Isle Royale and not much above Lake Superior. Holes Nos. XII and XV are on Sec. 16, T. 64, R. 38, and No. XVI is just over the line to the west on Sec. 17 adjacent. Of No. XII Mr. Stockly kept track down to 1038 feet which, as we know, was within sixteen feet of the bottom, and although the drill house with boxes, etc., was burned, I was able to get a few scattered samples, especially some which are without doubt from the very bottom of the hole, at 1054 feet, and thus to see that the bed of porphyry had not changed from what it was at the bottom of hole No. XVI. The remainder of these three holes were drilled after Mr. Stockly left the island, and the records may not have been so carefully kept, but they agree so well with each other and with Mr. Stockly's record, that I think we may depend upon them in a general way very well.

A word should be said as to how the samples were kept. Boxes were made the width of a board and about five feet long, divided by strips of wood into partitions the width of a drill core. There were generally five rows, so that if all the core was saved there would be just 25 feet of it in a box. But the amygdaloids and softer beds ground away somewhat into sludge, so that sometimes there would be more than twenty-five feet of strata represented in the box. The depth in feet for every raising was placed alongside the sample, on the partition, in pencil; the number of the hole, and the top and bottom depth represented were marked on each box. Thus, while there is some liability to error in the location of a sample, it is likely to be confined to five feet, and if not to that, at least to the range of the box. The samples in the top of hole No. XIII, from 31 feet to 113 feet, got mixed. The holes are located by survey on the map of the Wendigo property (Pl. III) and the altitudes were obtained by Y level. In the table below, their locations and elevations are given, *Table of Drill Holes of Wendigo Copper Company.*

1. No.	2. Lat.	3. Dep.	4. Sec.	5. T.	6. R.	7. Alt.	8.	9. Distance apart. Chains	10. Feet.
I.	S. 9.55	E. 22.21	¼ S., 20:21	64	38	163.7	XII	--------	-------
II.	S. 19.95	W. 15.51	{ Cor., 21:22 Cor., 28:27 }	64	38	407.0	XIV.	19.70	1300
III.	N. 4.18	W. 0.37	¼ S., 20:21	64	38	231.0	XIII.	23.00	1518
IV.	S. 0.64	W. 6.02	{ Cor., 21:22 Cor., 28:27 }	64	38	194.0	III.	26.90	1775
V.	N. 21.09	W. 7.83	{ Cor., 21:22 Cor., 28:27 }	64	38	56.0	I.	23.00	1518
VI.	S. 45.28	E. 45.23	{ Cor., 21:22 Cor., 28:27 }	64	38	341.0	V.	31.70	2092
VII.	S. 65.70	E. 65.80	{ Cor., 21:22 Cor., 28:27 }	64	38	262.6	IV	19.60	1293
VIII.	S. 0.93	E. 8.85	{ Cor., 27:26 Cor., 31:35 }	64	38	376.3	II.	27.40	1808
IX.	S. 28.16	E. 29.22	{ Cor., 27:28 Cor., 34:35 }	64	38	232.5*	VI.	36.40	2402
X	S. 50.19	E. 51.13	{ Cor., 27:26 Cor., 34:35 }	64	38	206.7	VII.	28.00	1848
XI.	S. 0.39	W. 11.54	{ Cor., 35:36 Cor., 2:1 }	64 63 }	38	143.0	VIII	24.00	1584
XII.	N. 9.36	E. 6.31	¼ S., 16:17	64	38	10. ±	IX	33.60	2218
XIII.	S. 2.63	E. 2.24	{ Cor., 17:16 Cor., 20:21 }	64	38	216. ±	X.	29.90	1973
XIV.	N. 24.00	E. 1.77	{ Cor., 17:16 Cor., 20:21	64 64 }	38	198. ±	XI	33.20	2191
XV.	N. 13. ±	E. 13. ±	¼ S., 16:17 }	64	38				
XVI.	N. 3. ±	W. 2. ±	¼ S., 17:16 }			20 or less	-----	--------	-------

* Measurements began at rock, *i. e.*, with an altitude 202.5 ft.

The A holes (13A, 4A, 7A) were bored from the same setup at an angle of 45° to the NE. No record of 4A nor of 7A was kept.

In column 1 are the holes in numerical order; in column 2 the distance of the drill hole north; in column 3 its distance east or west in chains from the quarter section post or section corner given in column 4. For XV and XVI the locations are only approximately scaled from note book of A. C. Lane. We have in column 5 the township. The range is always 38. In column 7 is the altitude, close estimates merely for holes XII to XVI; in 8 the holes are arranged in order from NW to SE. Their distance apart in the direction N. 30° W. is given in chains in column 9; in feet in column 10.

and the distances between them projected on a line running N. 30° W., which Stockly took as the direction at right angles to the strike, after careful observations at the holes, as well as at a number of test-pits between the holes. These distances are scaled from a blue print, the original map not being extant, and are liable to an error of 1:120. He found the dip in general to be about 15°, and in particular, from observations on the Minong trap in No. 5 tunnel and in No. 1 drill hole, he determined the dip as 14° 15′. These figures agree fairly with my observations, as recorded on the map of Isle Royale and in the geological column, except that I thought I observed that the dip increased slightly on the N. W., and especially on contact planes near the shore I got some good observations of 18°. On the whole, we cannot pretend for our work a greater accuracy than within 1 per cent. The dips derived from the correlations are given in connection with the geological column.

CHAPTER III.

THE SUCCESSION OF ROCKS.

§ 1. Introduction.

It is my object in this chapter to give an account of the succession of rock beds on Isle Royale revealed by the borings of the Wendigo Company, and by outcrops, and in this connection I shall try to give such an account of the rocks as may be understood by any intelligent mining man or explorer. Many of them are exceedingly fine grained, and their true mineral composition can be found only by examining thin sections under the microscope. The detailed account of microscopic work, however, and other technicalities, will be left to later chapters, or, where such may best be introduced in this chapter, it will be in finer print. I shall at the same time give my correlations with the beds on Keweenaw Point, and my reasons for the same, in so far as they are not too technical.

A. Mineral ingredients.

The rocks of the island are a set of old lava flows, and of sediments apparently derived almost wholly from the lavas or from similar rocks. The mineral ingredients of these lavas are often too fine grained to be recognized with the naked eye, and consequently a fuller description will be left until the petrographical chapter. For the present it will be enough to recognize among the original minerals, *i. e.*, those not produced by alteration:—

Feldspar, light colored, with light reddish or greenish tints due to alteration. Often on the cleavage faces fine parallel lines can be detected, and such feldspars contain less silica. The more siliceous feldspars are generally in shorter rectangles.

Quartz, often secondary, like glass and hard.

Augite, not easy to recognize and often altered, dark-colord. In the coarser basic, *i.e.*, less siliceous rocks augite is the main mass of what surrounds the feldspar. When there is a good deal of it, the feldspars lie in crystalline patches of it which when broken show a cleavage, and reflect the light in patches. This gives the lustre-mottled appearance characteristic of the Greenstone, and such rocks have been called ophites. In such cases, between the augite patches are more easily decomposed substances, and the consequence is that, on weathering, the surface of such a rock will have a peculiar pock-marked, lumpy look, which made Foster and Whitney call the rock "varioloid greenstone." Plate VII shows the general appearance of an exposure of this lustre-mottled rock, and a pocket lens will bring out the pock-marked appearance. The augite was often mistaken by early writers for hornblende. There is practically no hornblende visible in the Isle Royale rocks.

Olivine. Another mineral abundant in the Isle Royale rocks is olivine, which is hard to recognize in its fresh state, in fact hardly occurs fresh, but weathers into red micaceous specks which are easily noticed, and at other times changes into serpentine, a dark green substance. Iron ores may occasionally be recognized as black specks, generally magnetic with a black streak, *i. e.*, magnetite. Hematite gives the red color to many rocks; menaccanite has not been recognized with the naked eye. We must avoid a full description of all the minerals of alteration here, but shall refer to them in the chapter on petrography, Chapter VI., and shall merely remark here that, while the familiar epidote and calcite and chlorite occur everywhere, analcite and datolite seem to be more common in the rocks that are not very augitic.

B. Variations in flows.

The lava flows vary decidedly in chemical character and in structure, not merely as between successive flows, but in different parts of the same flow, and some general account of these variations is necessary. Then, again, the flows are millions of years old, and have been more or less weathered and altered. This introduces a new class of variations.

(*a*) *Variations between different flows.*—As an example of the class of variations which appear on comparing different flows, we find in these lavas a great range in the amount of silica, some of the beds being quite acid, that is to say siliceous, others much less so. In a general way we may say for these rocks that the less silica a rock has (secondary impregnations not counted), the less likely it is to have white or light red, yellowish or light flesh-colored tints, and the more likely it is to have dark colors —grey, green, red or purplish. The less siliceous it is, the more readily fusible. Experiments show that this is true for the slags corresponding to lavas, and consequently the lavas which are less siliceous will solidify more slowly than the acid, and hence will spread out into more extensive sheets and be coarser grained, for the same thickness of sheet. They are also heavier, and contain more iron, lime and magnesia, and generally less of soda and potash. The bubbles formed by escaping gas, which when later filled with minerals are called amygdules, are likely to be larger and more clearly defined, and less like irregular pores.

Owing to the lack of a lustre-mottled texture and perhaps to their more rapid cooling, the less augitic rocks generally present a finer and more compact appearance, they break more cleanly, and with a smoother conchoidal fracture, and are more smoothly, abundantly and conspicuously jointed. The jointing often divides them into columns. The "ashbed" diabases, for example, indicate their relatively less augite in these ways even to the naked eye.

(*b*) *Variations in the same flow.*—Here we find great differences in texture and composition. Near the margin the flow is finer grained, the contrast being more marked in the basic flows. The crystals which began to form while it was still moving, especially the feldspar and the olivine, are conspicuously in contrast with the rest of the rock, in which the eye can recognize no grain, but which looks like glass or porcelain. These marginal forms might naturally be called fine grained porphyritic trap, to distinguish them from the central forms which are coarser and have not so marked a distinction between the crystals formed before and after the bed came to rest, and might be considered different flows, if one were not careful. Of course a thin flow may have only the marginal form.

Then again at the top of the flow there is usually a belt of rock known as amygdaloid, which was originally full of bubbles of gas. The places of these bubbles have since been filled in with various minerals, as such porous layers allowed freer percolation of water. These amygdaloid layers will naturally be more sharply defined at the top than at the bottom and are of such importance as the repositories of copper, that the mining man's record of a boring is generally of an alternation of amygdaloid and trap, with occasional sandstone or conglomerate. This statement applies to the Keweenaw Point records also. But in correlation, such a record is not sufficient, as sometimes small flows will be amygdaloidal throughout, and so a belt of amygdaloid may be merely the top of one flow, or may be several small flows; it is by no means always easy to tell which, even in the drill cores, for a section through the ropy top of a modern lava field would show some puzzling alternations, and, moreover, the amygdaloid beds being soft, are much ground away.

Furthermore a tendency shows itself distinctly, as for instance in the flow which occurs in drill hole No. VIII from 196 feet down, for the lighter feldspar to gather at the top (Ss. 15354 to 15358), and for the augite to be more abundant at the bottom, of the same bed. This tendency cannot show itself at the margins where the cooling is too quick for it, but in the larger flows there is often, about two-thirds of the way from the top, a streak which is quite poikilitic or lustre-mottled, whereas the top is quite feldspathic.

C. Classification. Volcanic rocks.

We may then, for the naked eye, divide the lavas according to their acidity, into

1. *Quartz porphyries*, with distinct hexagonal pyramids of primary quartz, which often give nearly square outlines, in a porcelain-like groundmass which is generally reddish and light colored. The fracture is clean and conchoidal, if there are not too many porphyritic crystals, and the jointing is abundant and smooth, breaking the rocks up into angular fragments.

2. *Felsites*, with groundmass as above, but with no porphyritic quartz, the porphyritic crystals, if any, being of feldspar. Curious rounded forms (spherulites; see Chapter VI) occur in the Minong upper bed (p. 18). The felsites may be divided into felsophyres, and felsophyrites or felsite porphyrites, according as the feldspar is unstriated or striated.

3. *Melaphyre porphyrites*, with much striated feldspar which generally appears more or less porphyritic, usually greenish, more rarely reddish; the flows have a strong tendency to fine grain, smooth fracture and well developed joints, and are dark colored and

frequently have conspicuous reddish specks of altered olivine; they tend to have a very scoriaceous upper surface, "ashbed," with red sedimentary fillings of clay, etc.; the amygdaloid pores are smaller and more irregular than in the more basic rocks, and less completely filled, the secondary zeolites which fill them being often analcite and datolite; chalcedony is common. These are the "ashbed" diabases of Pumpelly and very nearly the diabase porphyrites of Irving, but since I find as a general rule that altered olivine in large distinctly porphyritic crystals, altered to a red micaceous substance, is a pretty constant ingredient in these rocks, I presume Irving called this substance altered augite. This it would be very convenient to do from a systematic point of view, but the original mineral is certainly more often olivine. Moreover, this melaphyre porphyrite may occur in the same flow with more basic types next to be described, and in fact can hardly be distinguished from marginal forms of other, more basic flows, which are probably included among Irving's diabase porphyrites. But the melaphyre porphyrite is not quite so dark, nor so heavy.

4. *Melaphyre ophites.* These are the same as the lustre-mottled melaphyre, varioloid greenstones, and olivinitic melaphyres and diabases of previous writers. But the olivine is a microscopic constitutent, even though the rocks are distinctly more basic than those of the preceding group. It was always abundantly present, but is only rarely visible to the naked eye. It is the crowding out of the olivine from the augite patches, which in a bright light often appear irregularly lustrous and make no objections to enclosing the feldspar,—that gives the characteristic mottled texture. The term ophite, in allusion to the resemblance to the mottlings of a snake, is a short and convenient term originally applied by A. Michel Lévy to similar French rocks, which I shall use interchangeably with mottled and lustre-mottled melaphyre.

5. *Melaphyre dolerite.* This is a term which I apply to certain parts of flows, rather than to indicate a certain basicity. Near the center of certain of the thicker flows are streaks of this texture, in which the coarse grained feldspar and augite are both well crystallized, in similar dimensions, and there appear to have been interstices between them which are now filled with chlorite.

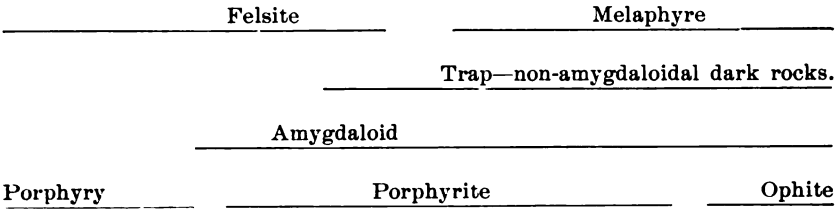
D. Sedimentary rocks.

We pass next to the sedimentary rocks of Isle Royale. These vary, according to their grain, from coarse conglomerates, so coarse that we can hardly tell if certain pebbles are not really lava flows, to red shales. The character of the fragments varies, from the angular fragments of the breccia bed, the irregular scoria of the "ashbed," e. g., down in drill hole No. IX, 279-291 feet, and the conchoidal angular fragments of the true volcanic glass ashes (S. 15236), to the rounded pebbles of the conglomerate bed, and the rounded grains of the sandstone. In general there is much more basic material in these beds, i. e., grains of augite and feldspar and pebbles of porphyrite and melaphyre, than we are wont to see in fragmental rocks, bût on the other hand the proportion of basic material is less than that of basic lavas among the lava beds. This may be due to the greater durability of the acid rocks, or also it may be due to the fact that the acid lavas having been at the time of their protrusion more viscid than the basic, were more likely to pile themselves up, so as to be more exposed to attack by the waves. A deep red color is characteristic of all the sedimentaries, and as this color is due probably to oxidized iron from the associated igneous rocks, and to the fact that there was no vegetable matter to reduce the iron, it has more than accidental significance.

E. Field names of rocks.

Even in our detailed survey of the geological column as derived from the drill borings, which is planned to be intelligible for those who work only with the naked eye, I cannot deny that in many cases I have received aid from the microscope, but I have made only those distinctions, and used only those names which can, I believe, be used by the field observer, after he has had a little special acquaintance with the rocks. I do not wish to be understood as maintaining that the particular grouping and divisions that I have made here will be found sufficient or even as plain in some other region. There are a large number of rock names, beside those strictly technical ones, which can be applied only after a thorough investigation of a rock —names from which a selection must be made by the worker in the field, to express such important characters as he can observe in the field. As we have already said above, the very same flow may differ in many ways at its margin and at its center, and an ophite may be easily recognized as such in a thick flow, while in a thinner flow the same structure requires a microscope for its recognition, though even then there are often suggestive hints in the character of the decomposition, which may guide the experienced observer. In some other region perhaps, the presence or absence of olivine may be a feature upon which many other features depend, but in our rocks the altered olivine is more conspicuous, if not originally more abundant, in the porphyrites than in the ophites.

The field observer may in some cases be able distinctly to class a rock as ophite or something else, in other cases he cannot do so. In some cases he may be quite certain whether a given rock is a quartz porphyry, a quartzless porphyry, or a porphyrite (with predominant soda-lime feldspars), and in some cases he must fail. There are, indeed, flows which stand on the border lines, where only the most careful and systematic application of an arbitrary definition will put them into one class rather than into the other. For the field observer, therefore, it is necessary to have overlapping names which will cover such cases as these, and the following scheme, I believe, is sufficient for field use.



If a special term is needed for the coarser forms of basic rocks, dolerite is far preferable to diorite, and a proper gabbro does not appear in place on Isle Royale, so far as I know.

§ 2. Rocks south of the drill holes.

In giving the succession of the rocks, we shall begin at the top or youngest bed, as that is the way Marvine reckoned the Eagle River section on Keweenaw Point with which we wish to compare the Isle Royale section. That is the order, too, in which the beds are met and numbered in drilling, and in sinking shafts like the Tamarack, or in driving adits like the long one at the Copper Falls mine. In numbering and measuring, we shall call 0 the top of drill hole No. XI, where we have the highest trap observed. We may have traps indeed south of this, but probably not, as south of

Cumberland Point no trap has been observed, nor south of Hay Bay, and hole No. XI lies on a line joining these points and considerably southeast of the line of strike of the extensive outcrops of conglomerate on Cumberland Point, between Grace Harbor and Rainbow Cove. According to the correlations here advocated there should at least be the horizon of the Lake Shore traps of Keweenaw Point to the south of hole No. XI, for it must be remembered that the beds farthest north on Keweenaw Point correspond to the beds farthest south on Isle Royale. The occurrence of beds on or near Isle Royale corresponding to the Lake Shore traps cannot be absolutely denied, for they may be under the waters of Lake Superior, or may pass through the drift-covered stretch extending from Rainbow Cove to Siskowit Bay. But the Lake Shore traps are not, as I believe, persistent on Keweenaw Point, rapidly diminishing, and finally disappearing to the southwest, in harmony with a general law. Where they go inland south of Silver Creek, in T. 58, R. 32, they are much narrower than they are farther out on the point, and around Portage Lake no trace of them is found. Consequently we should not, in the absence of any confirmatory evidence, be justified in assuming that they spread to Isle Royale, especially as they represent the last effort of the volcanic activity.

The southeast shore of Isle Royale is lined with conglomerate and sandstone ledges, and is about 24,395 feet from the southeast corner of Sec. 27, T. 64, R. 38, in a direction S. 30° E., or (as drill hole No. VIII is 340 feet S. 30° E. from the same corner) 24,055 feet from No. VIII. Our conclusions as to the rocks that occupy the space between this southeast shore and drill hole No. XI must be largely hypothetical, both as to their thickness and as to their character, but it seems to me there is some reason to believe that a fault runs as indicated on the map, through the low land connecting Rainbow Cove, Lake Feldtmann, and Siskowit Bay. The reasons are as follows:

(1) There is a difference in the attitude of the conglomerate of the two sides of Rainbow Cove that indicates some disturbance between them. The end of the point at the southeast end of Rainbow Cove is made of coarse conglomerate with occasional layers of coarse sandstone, which has a dip of 8° to 9° almost due south. Imbedded pebbles of the traps, melaphyres, amygdaloids, and

especially of a coarse porphyrite with large feldspar crystals in a dark base, are very numerous, continuing along the south side of lot 2, Sec. 30, T. 63, R. 39. Whereas on the other side of the cove, the point between Sec. 14 and Sec. 23, T. 63, R. 39, has a similar conglomerate, with dips; 10° to S. 30° E., 10°-12° to S. 20° E., 15° to S. 25° E., 13° to S. 25° E., 14° to S. 30° E., and the like. This indicates some disturbance between these two conglomerates. I have also thought of an unconformable overlap, or of a fault, the continuation of that coming down from the fault on Huginnin Cove, as the explanation of this.

(2) On the other end of this southernmost shore we have, across Point Houghton, dips averaging 20½° to the S. E., the formation being a rather uniform red sandstone, while a similar sandstone which occurs on Wright Island and on the other islands on the north side of Siskowit Bay, has dips of only 7°, 8°, 9°, etc. Now we find on the south side of Lake Superior suggestively similar relations between the dips,—say of the south trap range of the Ontonagon valley, and of the main range.

(3) The conglomerates of the point south of Rainbow Cove are continued in a ridge which runs south of Lake Feldtmann through Secs. 16 and 15, T. 63, R. 38. It looks very much as if this ridge might be a repetition of the conglomerate belt which outcrops north of Rainbow Cove.

(4) Except by some such fault there is no accounting for the topography. There is nothing exceptionally resistant in the beds of Point Houghton, so far as one can see, which should enable them to withstand the preglacial erosion as a prominent ridge, and elsewhere on the island the rule is that the sandstones run in the valleys or underneath protecting trap. It will also be noticed in the Lake Survey soundings of Siskowit Bay, how quickly the water deepens to the northwest of the Siskowit islands, indicating an old valley there with a steep cliff (fault scarp?) on the southeast.

(5) Finally, such an assumed fault seems to be analogous to other faults of the island, as the one at Chippewa Harbor, p. 41 *et. seq.* We feel justified, therefore, in assuming its existence, though the uncertainty attending it is another good reason for taking our starting point on that side of it which is the more important, as any change in our views as to the fault will produce less change

in our work. If we draw the fault through the low ground, as suggested, it will very nearly divide the territory between drill hole No. VIII and the lake shore into halves (distance taken as 11,860 feet). Then, assuming the dip of 12° 20′, which is the dip found between No. X and No. IX, as the general dip, and it agrees well with the observations on Rainbow Cove and Siskowit Bay, and subtracting 300 feet to allow for the greater altitude of drill hole No. VIII, which is 376 feet above the lake, we shall have (11,860 x .219 = tan. 12° 20′ = 2,584 — 300) about 2,300 feet of rock measured vertically above drill hole No. VIII, represented on the island. But, as we shall soon see, drill hole No. XI is 1,202 feet vertically above No. VIII, leaving us 1,098 feet of conglomerate and sandstone above No. XI. Applying a correction to reduce this vertical width to thickness perpendicular to the surface of the beds, we have 1,073 feet (1,098 x 0.977 = cos 12° 20′), say about 1,100 feet of sandstone on the north side of the fault, and about 2,600 feet of conglomerate and sandstone southeast of it, in each case with conglomerate at the base (12,200 feet x sin 12° 20′ = 0.2136 = 2,606 feet).

How much of this section is repeated by the fault we do not know. On the point north of Rainbow Cove there is apparently over 600 feet of conglomerate exposed (3,000 feet x sin 12° 20′ = 0.2136 = 641 feet). If this is the same conglomerate as that south of Lake Feldtmann, we may assume:

2,000 feet.	Red sandstone of Point Houghton, corresponding to the series found around Portage Lake from the old to the new Atlantic stamp mill (Sec. 34, T. 55, R. 34, to Sec. 20, T. 55, R. 35), and near the Portage Lake Ship Canal.
600 feet.	Conglomerate, with the cement often very calcareous, color prevailingly bright red, pebbles of all the range of lavas the melaphyres and porphyrites quite common, agate pebbles like the agate pebbles which occur in the Minong trap, not rare. This I take to represent both the "Outer" and the "Great" conglomerate of Keweenaw Point, the "Lake Shore" trap not appearing.

§ 3. DRILL HOLE RECORD.

DRILL HOLE NO. XI.

Top of No. XI, dip assumed 12° 20′; cos dip=0.9763.

The reasons for the assumption of this dip will be stated when there shall have been enough of the column given to include the part for which a given dip is assumed, at which time the reasons can be given without anticipating facts. (See end of record of this drill hole.) The *vertical* width of the beds, i. e., along the drill holes, is given in feet in the left hand column without parentheses (N. B. not the *horizontal* width which Marvine gives), and under it in parentheses is given the true thickness as found by subtracting a correction equal to (vertical width) × (1-cos dip). In the main body of the text follow, next, numbers that denote the limits, in feet, of the several beds below the tops of their respective drill holes. Then follow, in parentheses, high numbers which refer to the thin-sections of rocks from the respective beds; collection of Michigan Geological Survey.

17+	0–17; (Ss. 15544–5). **Ophite;** fine grained, massive, with red and white fine grained veins; lustre-mottlings visible. This is near Marvine's bed No. 7, Eagle River section.*
73 (71)	17–90; (Ss. 15546–63). **Conglomerate;** red with calcareous cement and a great variety of pebbles; the acid quartz porphyry predominates, but felsites, porphyrites and melaphyres are also present. Marvine's bed No. 8.
6	90–96; (Ss. 15565–6). **Melaphyre,** thin and amygdaloidal, with chloritic amygdules; slightly ophitic.
7	96–103; (Ss. 15567–8). **Melaphyre,** amygdaloidal. While not coarse enough, that is not thick enough flows to show the characteristic texture to the naked eye, the two small preceding beds appear to belong to the melaphyre ophites, with calcite, quartz and zeolite amygdules.
21 (20)	103–124; (Ss. 15569–72). **Melaphyre,** ophite. The upper 5 feet are amygdaloidal, and make, with the above two small flows, one amygdaloid belt.
0	A very thin **Sediment** with a calcareous cement underlies this bed.
13	124–137; (Ss. 15573–5). **Melaphyre,** amygdaloidal. Marvine's bed No. 16.
9	137–146; (Ss. 15576–9). **Conglomerate;** red, with the usual porphyry and felsite pebbles. Perhaps equivalent to Marvine's bed No. 17.

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* Geol. Sur. of Mich., I, Pt. II, p. 120.

	8	146-154; (Ss. 15582-3). **Porphyrite** (?), amygdaloidal. I think it not impossible that this is merely a boulder in the conglomerate, as we have the conglomerate again interrupted by something similar (S. 15585).
	5	154-159; (S. 15584). **Conglomerate,** as above.
	2	159-161; (S. 15585). **Porphyrite,** like S. 15583.
61 (59)	37 (36)	161-198; (Ss. 15586-99). **Conglomerate;** continued, growing finer and passing into red sandstone in the last 7 feet. It seems to me quite possible that we have in these last 59 feet only one bed of conglomerate which will correspond about to Marvine's bed No. 17, but his sandstones, Nos. 17, 19 and 21, are separated by single flows, and are more or less conglomeratic, and our conglomerate may represent the whole of them.
11		198-209; (Ss. 15600-4). **Melaphyre,** amygdaloidal.
3		209-212; (Ss. 15604?-5). **Melaphyre,** glassy; in contact with sediment: perhaps a surface coil of the trap next below.
10		212-222; (Ss. 15606-9). **Melaphyre,** ophite; amygdaloidal and feldspathic.
44 (43) 0		222-266; (Ss. 15610-19). **Melaphyre,** ophite; about 17 feet of amygdaloid at top and 9 feet at the bottom. Perhaps they are two minor flows. We have distinct **Sedimentary** matter in the parting at bottom.
9		266-275; (Ss. 15620-1). **Melaphyre,** amygdaloidal; from 272 to 275 the amygdules are not so prominent.
8		275-283; (Ss. 15622-3). **Melaphyre,** amygdaloidal; 2 feet amygdaloidal at top, the rest compact. It is really a fine grained ophite, as most of these beds are, but they are too thin for the structure to develop so as to be visible to the unaided eye.
19.5 18		283-302.5; (Ss. 15624-6). **Melaphyre,** amygdaloidal; the upper 9 feet amygdaloid, with *copper* (at 289 feet), prehnite and quartz.
	2.5 (2)	302.5-305; (Ss. 15627-8). **Shale,** red, indurated; in vein-contact with trap. Dip measured on drill cores, 14°.
8	6	305-311; (Ss. 15629-33). **Conglomerate,** with pebbles of melaphyre as well as of felsite; toward the bottom fine-grained and epidotic. Dips measured on the cores, 18° and 14°. This is about the same distance above the bed that we correlate with Marvine's bed No. 35, as Marvine's No. 21 is. The very fine and partly indurated character of Marvine's bed No. 21 matches our two feet of red shale.
16.5		311-327.5; (Ss. 15634-8). **Melaphyre,** ophite; amygdaloidal; is markedly amygdaloidal for about 4 feet, then mildly spotted—somewhat more so at the bottom. The contact with the conglomerate dips 19°. If the overlying bed is the same as Marvine's No. 21, this may represent bed No. 22, which is mentioned by Irving as a typical representative of his ordinary diabases.*

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* Copper-Bearing Rocks of Lake Superior, Mon. V, U. S. Geol. Survey, 1883, p. 65.

16.5 (16) 327.5–344; (Ss. 15639–42). **Melaphyre,** ophite; amygdaloidal for the first 7 feet.

5 344–349; (Ss. 15643–4). **Melaphyre,** amygdaloidal.

13 349–362; (Ss. 15644–6). **Melaphyre,** ophite; about 7 feet at the top and 1 foot at the bottom are amygdaloidal.

8 362–370; (Ss. 15647–50). **Melaphyre,** ophite; about 3 feet at the top are amygdaloidal.

14 370–384; (Ss. 15651–5). **Melaphyre,** amygdaloidal; possibly two flows.

5 384–389; (Ss. 15656–7). **Melaphyre,** amygdaloidal.

7 389–396; (Ss. 15658–60). **Melaphyre,** amygdaloidal.

61 (59) 396–457; (Ss. 15661–8). **Melaphyre,** ophite; first 20 feet or more amygdaloidal, then a fine grained black trap, with the lustre-mottling showing somewhat.

1 457–458; (Ss. 15669–71). **Sandstone,** dark, basic; porphyry fragments not marked. This may represent Marvine's bed No. 26.

(24) 458–482; (Ss. 15671–6). **Melaphyre,** ophite; first 6 feet an amygdaloid with datolite, then a fine grained black trap, finally distinctly mottled. At the base there is a **sediment.** Compare Marvine's bed No. 27.

10 482–492; (Ss. 15677–9). **Melaphyre,** ophite; first 5 feet amygdaloidal; below that a fine grained trap, the bottom of the bed apparently gone.

1 492–493; (Ss. 15680–1). Seam of red **clay flucan,** perhaps marking a fault. A fault throwing the south side down, and hading to the south would make a gap which we could not detect (see p. 71, Fig. 5), but we may be reasonably sure that there is no fault which would lead to a repetition farther north of the beds we have already described, for these consist of a number of sandstones and conglomerates with thin basic melaphyres of the ophite type, whose texture is sometimes coarse enough to be recognized, and these we do not again encounter. After two more conglomerates, we come to a series of somewhat less augitic flows, with nonfelsitic conglomerates.

6 493–499; (Ss. 15683–99). **Conglomerate,** with porphyry, felsite, and trap pebbles, and calcareous cement; dip about 13°–14°.

1 499–500. **Clay;** another seam, which may indicate a fault. Thus, as the conglomerate may be bounded by possible fault planes above and below, we cannot be certain of its correlation, and it may be a repetition of some higher or lower conglomerate, but relatively to our general correlation it is nearly in the position of Marvine's No. 28.

7.5 (7) 500–507.5; (Ss. 15690–2). **Melaphyre,** amygdaloidal.

3.5 (3) 507.5–511; (S. 15693). **Amygdaloid;** may belong to the flow above or to that below.

14 511-525; (Ss. 15694-6). **Melaphyre,** ophite; more or less amygdaloidal, especially the first two feet.

Here we will pass for a moment from hole No. XI to hole No. X, to compare the two. Assuming that hole No. XI at 525 feet is equivalent to hole No. X at 113 feet, which will make a difference of 412 feet: adding the excess of altitude of No. X over No. XI (206.7 — 143 = 64 feet), makes 476 feet, and dividing by the distance between them, 2,191 feet, we have 0.218 as tan of dip; i. e., the dip is 12° 20′.

The rest of No. XI we correlate as follows:

Hole No. XI at 532 feet, contact, is equivalent to hole No. X at 123 feet; difference, 409 feet. Hole No. XI at 536 feet, contact, is equivalent to hole No. X at 133 feet; difference, 403 feet, and the characters of the beds assumed to be equivalent harmonize very well.

We are led to this correlation by the fact that we cannot match, in No. X, the conglomerate at 493 feet in No. XI, unless possibly at 469 feet, in No. X, and if we did that the adjacent beds, e. g., at 457 feet, would not correspond. Hence we must find a match for the first beds in No. X, i. e., at 109 feet (for the first 107 feet are in a surface deposit, old lake bottom, fine red sands and clays), below 493 feet in hole No. XI, and we come upon the one given above, which is the best we can find. Moreover, this match gives the same dip for the beds that we shall find later for the correlation from No. X to No. IX,—one that agrees pretty closely with the dips measured on the drill cores. If the correlation is good but the dip really 13°, it would mean that the rock of No. XI had been upthrown about 29 feet, in which case our column would be that much too long. But there is absolutely no indication of any faulting in either direction. If the dip is steeper than we assume and the two holes do not overlap at all, we have made the column too short. (512)

DRILL HOLE NO. X.

10 113-123; (Ss. 15463-5). **Melaphyre.**

12 123-135; (Ss. 15466-9). **Melaphyre,** amygdaloidal; a trace of sand
0 at lower contact.

13 135-148; (Ss. 15469-72). **Melaphyre,** amygdaloidal; more compact in the lower 4 feet.

21 148-169; (Ss. 15473-8). **Melaphyre,** ophite; upper 9 feet amyg-
(20) daloidal, then more massive.

23 170-193; (Ss. 15478-88). **Conglomerate.**
(22)

This conglomerate contains abundant acid pebbles, of porphyry and felsite, and of melaphyre as well. This bed I take to be the conglomerate opened by the Island mine, as the two have a similar lithological look or character, and lie nearly in line of strike from each other. The Island mine conglomerate runs about 500 feet south of the north quarter post of Sec. 29, T. 64, R. 37, and has a steep dip (from 19° to 25°), considering its position. Again, near Siskowit Lake, 50 steps north of the southwest corner of Sec. 26, T. 65, R. 36, and down to the corner, we find along the same line of strike a conglomerate which I take to be the same bed. So it continues on, being probably the same as that indicated by Foster and Whitney at the southwest corner of the head of Rock Harbor, on Sec. 5, T. 65, R. 34. I think, however, that it does not pass through to Conglomerate Bay, but like other beds in this vicinity veers a little to the north and goes through the trough of Rock Harbor. It is barely conceivable that, if we turn and go in the other direction, by the time we shall have come to Grace Harbor all the overlying traps will have run out, and that this conglomerate will have merged in the general conglomerate of Cumberland Point. This conglomerate in drill hole No. X differs from those above it in that it carries a greater proportion of basic pebbles, especially of the immediately underlying melaphyre porphyrites, but it differs still more decidedly from any conglomerate within the first thousand feet beneath it, in that it still contains a considerable proportion of felsitic debris — more perhaps at the Island mine than at the drill hole. This contrasted relation of the conglomerates above and below this horizon holds good, so far as the meagre facts indicate, for the corresponding beds at the other exposures above mentioned. All these exposures, moreover, lie on the southeast flank of a fairly continuous ridge which is principally made up of the rocks which we have described as melaphyre porphyrites, similar to the "ashbed" type of diabase. Northwest of this porphyrite ridge we find a still more continuous ridge, the "backbone" of the island, which is made up of coarsely lustre-mottled rocks—ophites. It will be noticed, from what we have said, that not only the sedimentaries but the eruptives change their character, above and below the conglomerate horizon which we are studying. Above it we have a series of thin flows, generally largely amygdaloidal, but when coarse enough showing the mottling of the ophites, and interstratified with them numerous beds of siliceous sedimentary rocks. Below it, as we shall see, the beds are in general thicker and more massive, and less augitic (porphyrites), and the interstratified sediments and amygdaloids resemble those which form the hanging of the Ashbed type.

Now we have on Keweenaw Point at Eagle River and elsewhere a precisely similar series, only with the order from southeast to northwest reversed, but the stratigraphic order the same. I use mainly for comparison Marvine's Eagle River section, as I have been over and revised it and have collected specimens from it expressly for this purpose. Beginning from the uppermost trap bed actually noted (Geol. Sur. of Mich. I, Pt. II, p. 112) Marvine counts ten sandstones in the first 2,300 feet of the section horizontally, (i. e., 1,272 feet thick; *loc. cit.*, p. 124) to bed No. 35. This is the greater part of his series (c) which he however carries down somewhat farther to the first scoriaceous amygdaloid. In this part of the series the beds incline to be ophitic when at all thick, and the character of the formation generally matches the beds above the Island mine conglomerate. It will be noticed that for this part of the section we have on Isle Royale but half the thickness represented at Eagle River, the thickness to the bottom of the Island mine conglomerate being but 589 feet, but on the other hand we have six to eight of the ten conglomerates and sandstones.

Beginning with the flows immediately below Marvine's bed No. 35 and the Island mine conglomerate, we find a distinctly less augitic character in the flows as a whole, while the base of each flow remains somewhat ophitic in texture; we can recognize this change under Marvine's bed No. 35, in the Copper Falls adit, the Tamarack mine and elsewhere. In my reexamination of the Eagle River section I observed that the change really takes place there also at the point indicated. Then in all cases the first sedimentary bed we meet below the Island mine conglomerate, respectively below Marvine's bed No. 35, is distinctly of the Ashbed type, e. g., at 415 feet in No. X, Marvine's bed No. 44. Below this bed the traps are still less augitic, and they, together with their associated scoriaceous conglomerates, have in each case about the same thickness. Under this complex we find also, both on Isle Royale and on Keweenaw Point, the largest flow of the coarsest ophite that occurs anywhere in the series, the Greenstone.

Now I am well aware of the danger of purely lithological correlations, but in view of the fact that beds of the series which we have been studying have been followed for a distance along Keweenaw Point equivalent to that across the lake, in view of the fact that a basic lava sheet of 200 feet, yes, in some places of 1,000 feet thickness may be expected to spread a great distance, with some uniformity of lithological character, in view of the general parallelism both in sedimentaries and in traps, both above and below, there seems to be no reasonable doubt that the Island mine conglomerate is equivalent to Marvine's bed No. 35, or is, at least, at very nearly the same horizon.

I put in this last clause because if anyone should object that Marvine's No. 35 might have faded out and that another conglomerate might have formed on the Island at nearly the same point in the series, my arguments would not conflict with this hypothesis. As a matter of fact, however, the *indications* are that the bed we have just discussed is identical with Marvine's No. 35.

113 193–306; (Ss. 15489–501). **Melaphyre,** porphyrite. This is a
(110) pseudamygdaloid for the first 20 feet, that is, the amygdules are indistinguishable from decomposition spots. It is different from the ophites above, most markedly in microscopic characters, but also to the naked eye, for the feldspar is much more conspicuous and there is no lustre-mottling, as there would be very plainly in a bed of ophite of equal thickness. In other words the feldspar is large in proportion to the size of the augite. Light greenish seams and spots, and a generally lighter, more grayish green color may be noted on comparison. This would correspond to Marvine's bed No. 36.

It will be noticed in Marvine's description of bed No. 36 that the scoriaceous character of the amygdaloid is mentioned, which is characteristic of the less augitic melaphyres. Farther details as to the change in character must be left to the petrographic chapter. The feldspar is oligoclase instead of labradorite.

16 306–322; (Ss. 15502–5). **Amygdaloid.** This is a fine grained red amygdaloid, apparently the same kind of rock as the bed above, but a thinner flow.

0? Among the drillings at 321 feet were 2 inches; at 322 feet, 4 inches; at 323.3 feet, ½ inch of a basic **sandstone.** The driller's record threw no light on the occurrences, but from the gradually finer grain of the traps above and below them, I am led to believe that they all really belong at 322 feet, and that there is a bed of fine grained dark red basic sandstone there. Dip 14°.

3 322-325; (S. 15506). Perhaps another bed of **Amygdaloid.** At
(718) 325 a narrow seam is noted which may however be a fault.

7 325-332; (Ss. 15506-8). **Amygdaloid;** at 332 feet highly amygdaloidal, brecciated, and mixed with finer grained sediment; quite likely a slip.

6 332-338; (Ss. 15508-12). **Amygdaloid.**

77 338-415: (Ss. 15513-24). **Melaphyre;** of the porphyrite type at
(75) the top, but becoming darker and approaching the ophite type at the bottom. It is somewhat amygdaloidal down as far as 352 feet, beginning as a fine grained red porphyrite with amygdules of chlorite and a few of agate at the top. At 344 feet and 377 feet green rock was cut which would in the field prove, I feel sure, to be either rounded masses or irregular skeins, which are characteristic of this group, and are slightly more likely to be amygdaloidal than the adjacent rock. They are more decomposed, though this decomposition doubtless follows some primary feature, and are permeated with cavities lined with crystals of quartz and chlorite.

As we get toward the bottom the rock, which is firm and compact, and yields long drill cores, becomes darker, and finally somewhat lustre-mottled. *Copper* appears in paper-like sheets in the chlorite seams. This is probably Marvine's bed No. 43.
(806) Analyses of this bed will be found in Chapter IX.

11 415-426; (Ss. 15525-30). **Conglomerate.** This bed is the first of
(817) the scoriaceous conglomerates, otherwise known as ashbeds or scoriaceous amygdaloids. The matrix is very dark, of a deep maroon shade, generally speaking, very fine grained and argillaceous, and the pebbles are irregular masses of amygdaloid, like the beds with which they are associated. The line between the conglomerate and the underlying amygdaloid is extremely difficult to draw. This is the reason why these scoriaceous beds have been considered as extreme forms of amygdaloid, but there is no doubt that in the beds which I am now considering there is a large amount of detrital matter, almost exclusively from basic rocks. They are very calcareous.

This conglomerate corresponds very nicely to Marvine's bed No. 44—as well, indeed, as his bed No. 35 corresponds to the Island mine conglomerate. The underlying rock corresponds to Marvine's bed No. 45, being a melaphyre porphyrite, with a clean conchoidal fracture, as we shall see, and the immediately overlying bed is in each case indistinctly mottled. Marvine allowed eight beds between No. 35 and No. 44, but two numbers were allowed for beds unobserved, and none of the observations showed that Nos. 42 and 43 were separate beds, and in fact I inferred from the coarseness of grain and other things that in reality from No. 39 down to No. 43 was all one large flow (184 feet) corresponding so closely to our melaphyre in No. X (338-415, i. e., 75 feet thick) as probably to be the same flow. That left four beds in the Eagle River section, between No. 35 and No. 41, to correspond to our six beds, in each case with a thick flow at the base. From the top of Marvine's bed No. 35 to the top of his bed No. 44 is, according to Marvine, 273 feet. The corresponding distance in our column of rocks is (806–567) 239 feet, which is quite as close a correspondence to the general ratios (see table at the close of this chapter) as could be expected, 50 miles away, and eminently satisfactory. The correlation is made much stronger by the study, under the microscope, in Chap. VI, of the comparative coarseness of grain, and the change in the character of the feldspar.

57 (56) 426–483; (Ss. 15531-7). **Melaphyre,** porphyrite. This is one of the most acid of the melaphyres, really of the type of an olivinitic augite andesite. The smoother fracture, generally lighter, green color, abundance of not very large white porphyritic feldspar aggregates, and compact texture are well marked. This is the bed that we seem to find at the top of drill hole No. IX. (874)

We assume that No. X, 483 feet, is equivalent to No. IX, 49 feet, a difference of 434 feet. Subtracting the excess of altitude of No. X over No. IX (206.7-202.5*), 4.2 feet, we have 430 feet, which divided by the distance between them along the line of cross-section, 1973 feet, gives 0.217, the tan 12° 20′. This is the same as we had before, the two computations confirming each other and strengthening our correlations, which were in the first place purely lithological. In case this correlation is wrong, so that No. X and No. IX do not overlap, the resemblance noted being that of similar successive flows, we should have a steeper dip, or a fault. The correlation with the next hole north will give us a slightly steeper dip, about 13°. But a slight flattening of the dip going south is to be expected, and there is no reason at all to assume a fault. A fault the other way, producing a repetition of beds and leading us to exaggerate our column, is ruled out by the fact that the conglomerate, 415–426 feet in No. X, can be matched even approximately only at about 313-338 feet in No. IX, in which case we should expect to be able to match all of No. X and No.

*** The altitude of the surface is 232.5 feet, but the 30 feet of drift material first encountered were omitted in reckoning the drill hole depths.**

IX above these points, but the top of No. IX is this very acid melaphyre porphyrite of a type which has not appeared above 426 feet in hole No. X. However, we should point out the strong resemblance of the rocks around No. X, 483 feet; No. IX, 385 feet; No. VIII, 47 feet, in order that any one may, if he choose, try his hand at making them the same horizon repeated. I have been unable to do so without assuming arbitrary faults *ad libitum.*

DRILL HOLE NO. IX.

We then correlate the first 49 feet of No. IX with the bed of
melaphyre already described (Ss. 15386-9). The next bed is—
54 49-103; (30 feet of drift not counted) (Ss. 15390-7); corresponds to
(53) No. X, 483-508; (Ss. 15540-3). **Melaphyre,** porphyrite; red,
finely porphyritic, with an almost felsitic matrix; with
chloritic amygdules for the first 15 feet, then a grey trap like
the flow above.
49 103-152; (Ss. 15398-402). **Melaphyre,** porphyrite; to the naked
(48) eye much like the two flows above, though not so acid; at the
top about 20 feet somewhat amygdaloidal (chloritic).
18 152-170; (Ss. 15403-6). **Melaphyre,** porphyrite; first ten feet red
porphyritic amygdaloid. This bed has (at 164 feet) the same
(993) decomposed green, light colored spots, as in No. X, 344 feet.
44 170-214; (Ss. 15407-8). **Melaphyre,** porphyrite; not very acid:
(43) diabasic texture often conspicuous; red and amygdaloidal porphyrite at the margins.
8 214-222; (Ss. 15408-10). **Amygdaloid;** epidote needles, etc., in
the half-filled amygdules.
13 222-235; (Ss. 15411-2). **Amygdaloid.**
0 Seam or separation line of fine grained **sediment.**
44 235-279; (Ss. 15413-6). **Melaphyre;** more or less amygdaloidal,
(43) with laumonite and datolite.
(1,100)
12 279-291; (Ss. 15417-24). Ash bed and scoriaceous **conglomerate.**
The top of this bed is a very fine grained genuine ash, under
which for a foot or more it is like a dark red sandstone. Lower
we encounter a lot of laumonitic amygdaloid, and some samples
which show more clearly its characters as a volcanic breccia,
with intermingled sediment and scoriæ. It is much decomposed. Marvine's bed No. 63? Dips on drill cores 25°, 23°,
(1,112) with signs of cross-bedding.
22 291-313; (Ss. 15425-9). **Amygdaloid.** Some of the specimens

(21) look like ophites. They are all much decomposed, and it is barely possible they may all be part of the scoriaceous conglomerate.

15 313-328; (Ss. 15430-6). **Conglomerate,** scoriaceous. This contains green decomposed ash, and a calcareous cement. The three beds just described bear a striking analogy, in lithological character and stratigraphic position, to Marvine's beds No. 63 to No. 65, the "Ashbed" *par excellence.*

One of the above conglomerates would be No. 17 of Marvine's plate, i. e., the Hancock West conglomerate. There is, however, a fault in the Eagle River series at this point, and I am not sure but that No. 64 and No. 65 are really the same bed. Marvine applies one and the same number to cover both the Ashbed and the underlying melaphyre. The relative position to the beds already correlated is just as it should be. (See table at the end of this chapter.)

57 (56) 328-385; (Ss. 15437-41). **Melaphyre,** porphyrite; like the porphyrite above 485 feet in No. X, already described. I think it is the same bed as the one at the top of No. VIII, down to 47 feet, which it is also like. We pass then at this point from the record of No. IX to that of No. VIII. But there is a peculiarity about the record of the rest of No. IX that deserves mention. After some feet of amygdaloids and clayey seams with some *copper* at 413 feet, No. IX finishes below 427 feet in a large bed
(1,202) of ophite, the like of which we do not find in No. VIII until we get down to 196 feet. Either, therefore, one of these two correlations (that of 385 feet in No. IX to 47 feet in No. VIII or that of 427 feet in No. IX to 196 feet in No. VIII) must be given up, or we must suppose a remarkable wedging out of intermediate beds, or lastly we must suppose that a fault has cut out part of the record of No. IX. But the correlations are—microscopic evidence and all else considered—very good. Moreover, in the interval, drill hole No. IX shows marked signs of disturbance, especially between No. IX, 385 feet, and No. IX, 427 feet. At 408 feet there is some kind of a break with much decomposed and prehnitic rock; at 413 feet there is a seam with *copper;* at 420 feet a datolite vein; at 430 feet a brecciated amygdaloid. Therefore the last supposition seems most probable--that there is a fault. The character of a fault like the one here supposed depends upon whether the upper or the lower correlation gives the normal dip. If we assume as undisturbed the correlation 385 feet in No. IX, with 47 feet in No. VIII, and add to the difference (338 feet) the excess of elevation of No. VIII over No. IX (376.3 202.5, the altitude of the rock at No. IX; the surface of the ground is 30 feet higher) 174 feet, and divide by the distance between the holes

along the section (2,218 feet), we shall have 0.231, i. e., tan 13°, about half a degree steeper than the dips we have computed thus far in our section south of this point, but the same as dips computed at points further north (p. 71). On the other hand the deeper of the two correlations, 427 feet in No. IX with 196 feet in No. VIII, would give us 0.183 as the tan of 10° 20′. This is much flatter than anything we have reason to expect, and the inference is that the fault affects this correlation rather than the other. Thus we are led to the conclusion that if there is a fault it cuts No. IX, raising the lower part of it but not the upper. Hence it is a normal fault with northerly or westerly hade. Fig. 8 may represent it.

The indicated vertical upthrow of the lower side is 107 feet. Such a fault as we see from Fig. 8, if it came between the top of No. IX and its correlate in No. X, would there make a dip too flat. Hence the dip of 12° 20′, found above for the strata between No. IX and No. X, would have to be increased to 15° 10′. While, however, the dip might well be a little steeper, we should not expect it to be as much as that. Nor can we readjust the correlation of No. X and No. IX, as it is too marked in petrographic character We may of course imagine another fault with hade to south that has thrown the bottom of No. X back into position, of which fault there is, however, not the slightest direct evidence, or we may suppose in spite of the evidence of the dips that the flatter dip is the true one, and that, as explained on page 36, the fault hades south. It is, however, possible to imagine a fault such in strike that it will leave No. VIII, No. IX and No. X in undisturbed relation to each other at the top, and yet gouge out a piece of No. IX low down, having either very nearly the strike N. 45° W. or else having a very flat dip.

The matches on which this argument is founded seem, microscopic evidence and all things considered, to be the only ones possible, especially because No. VIII, 47 feet, cannot find a match in anything lower than No. IX, 385 feet. No. IX, 427 feet, should certainly appear in No. VIII, but cannot find a match nearer the surface than No. VIII, 196 feet.

A fault such as the one we are describing would not affect our record, however, as we are now about to pass from No. IX, 385 feet, to No. VIII, for it would cut No. IX below this point.

According to our correlation, the distance from the bottom of the bed corresponding to Marvine's No. 43, to the bottom of the bed corresponding to his No. 65, is (1202–806) 396 feet, while the corresponding distance in the Eagle River section is 573 feet—thicker in about the usual ratio, i. e. about 3:2. (See the end of this chapter.)

DRILL HOLE NO. VIII.

24 47-71; (Ss. 15335-7). **Melaphyre;** the top 13 feet amygdaloidal;
(22) intermediate type between ophite and porphyrite, not markedly
belonging to any subdivision of the melaphyres; like the flows
just below. It is correlated with and just about the size of
(1,224) No. IX, 385-418.

18 71-89; (Ss. 15338-9) **Melaphyre,** fine grained and amygdaloidal.
In No. IX the records are much mixed along here. There are
slide or flow contacts at 408 feet, 413 feet, 421 feet, with fine-grained,
red, chloritic, datolitic and prehnitic amygdaloids.
Here is where I have supposed that the fault above discussed
goes through.

14 89-103; (Ss. 15340-1). **Melaphyre,** amygdaloidal.

32 103-135; (Ss. 15342-4). **Melaphyre,** amygdaloidal.
(31)

11 135-146; (Ss. 15345-7). **Melaphyre,** amygdaloidal.

18 146-164; (Ss. 15348-9). **Melaphyre,** amygdaloidal.

32 164-196; (Ss. 15350-3). **Melaphyre,** amygdaloidal, perhaps largely
(31) pseudamygdules, of laumonite, chlorite and prehnite.

The flows above are all of moderate size and, though varying
somewhat, have the general habit of the less augitic melaphyres,
i. e., the melaphyre porphyrites. The microscope shows that
(1,347) they carry oligoclase feldspar.

77 196-273; (Ss. 15354-8). **Melaphyre,** ophite. This bed for 3 feet
(75) is very amygdaloidal, then coarser, with occasional chloritic
(1,422) amygdules, and becoming still coarser it shows the rusty
specks of micaceous altered olivine; toward the base it is fine-grained
with datolite veins. This matches very closely No.
IX, 427-468, which is so coarse when the hole ends that the
latter evidently stops in the middle of the flow.

57 273-330; (Ss. 15359-64). **Melaphyre,** ophite; like the flow above.
(56)

32 330-362; (Ss. 15365-6). **Melaphyre.**
(31)

15 362-377; (Ss. 15367-8). **Melaphyre.**

The above four flows steadily increasing in their relative thickness
toward the top flow, seem to belong to the same type.
Though belonging to the ophites rather than to the porphyrites,
they have peculiar microscopic characters of their own,
(1,524) and are not very ophitic.

42 377-419; (Ss. 15369-73). **Sandstone;** red, with 1 foot of conglom-
(41) erate at the bottom; in general quite uniform in grain; dark
chocolate red; sometimes brecciated, with small red veins; the
conglomerate at the base contains some felsitic debris.

Dips measured on drill cores 13°, 14½°, 15°, 16°, 15°; cross-bedding
of 23°. It is noticeable that the dips thus obtained from drill

cores tend to be larger than those from correlations, and this fine grained sandstone furnishes some good observations. Three explanations for this want of agreement are possible,—

(1) The drill holes may curve to the north. They are not likely under the circumstances, however, to curve in this particular way, and, if they did, the effect would regularly be more marked toward the bottom.

(2) The conditions of deposit may have been such that the sandstone was formed in some measure by accretions, building from northwest to southeast, so that each of the laminæ of which a bed was composed had originally a slight dip to the south greater than that of the bed itself as a whole. This is quite likely and is in harmony with the geological position of Isle Royale, with a mass of Archæan land to the northward of it.

(3) The difficulty may be with the correlations, which may have been made to give too flat dips by faults not otherwise to be detected, which run between the drill holes and throw the south side up. This also is quite within the range of possibilities, and when we have the sum of the whole series we shall estimate what effect this might have.

This sandstone is a more thorough sandstone than any other in the series, of like size, and its course seems to be marked by a line of depression from Grace Harbor and its creek through to the northeast end of the island, as indicated upon the map. This bed is about (1565-1202) 363 feet below the bed (847 feet) that we have correlated with Marvine's Ashbed, No. 65, and would appear to represent the "first sandstone below the ashbed," which Marvine supposes to lie in a covered place, 506 feet stratigraphically below bed No. 65, which is about the usual (p. 68) rate of shrinkage between Isle Royale and Keweenaw Point. On this assumption the sandstone at No. VIII, 440 feet, just below, would do well for No. 85 of the Eagle River section, which Marvine seems to correlate with the "Pewabic West," and says is 767 feet below the slide above the Ashbed, and is No. 16 of his plate of conglomerates facing p. 60.* It would be wiser probably, and more nearly true to the facts, to correlate both our sandstones together as indicating a weakening in igneous activity represented by all the sandstones in the Eagle River section from bed No. 79 to bed No. 85.

11 420–431; (Ss. 15374–5). **Melaphyre,** porphyrite; about 4 feet amygdaloidal at the top (we are back to the porphyrites once more), dark green, with reddish porphyritic crystals. Matches Marvine's bed No. 82.

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* Geol. Sur. of Mich. I, Pt. II.

0 431; **Sediment;** contact; Marvine's bed No. 83?

9 431–440; (S. 15376). **Melaphyre,** porphyrite; about 2 feet amygdaloidal at top; matches Marvine's bed No. 84, so far as size will permit.

4 440–444; (Ss. 15377–9). **Shale,** red. The grain is so fine that this

1,589 bed was taken to be a fine grained trap until the microscope revealed its character.

42 (41) 444–486? (Ss. 15380–1). **Melaphyre,** porphyrite; very acid specimen; little olivine or augite, and might also be classed with the more acid rocks; amygdaloidal for 5 feet at the top, then a typical greenish grey trap. The exact bottom of this flow is a little uncertain. It lies on another flow of similar lithological character (both remarkable, under the microscope, for the scarcity of olivine), both of which appear to occur at the top of drill hole No. VII, to which we therefore pass at No. VIII, 486 feet, making the latter equal to No. VII, 10 feet. It is obvious that as the sandstones above No. VIII, 444 feet, do not appear in No. VII, the correlation of the top of No. VII cannot be sought above these sandstones. If we figure out the dip as before (486–10) = 476 minus the excess of altitude of No. VIII over No. VII (262.6-376.3) 114 = 362 feet, which divided by the distance, 1,584 feet, is 0.229, again the tangent of about 13°, (really about 0° 5′ less), only .002 from the tangent of the dip as computed between Nos. VIII and IX. So small a difference hardly requires any explanation. The boundary line between the two flows is not well defined; there may be a little faulting between No. VIII and No. VII, or the dip may vary a trifle from some other cause.

DRILL HOLE NO. VII.

73 (71) 10?–83?; (Ss. 15283–8). **Porphyrite;** like the flow above, about 6 feet at the top amygdaloidal; has irregular amygdaloidal streaks, and occasional seams of laumonite; the porphyritic feldspar clumps are very well marked.

26 83–109; (Ss. 15289–92). **Porphyrite,** amygdaloidal; *copper* in amygdules (at 83 feet), and in veins with prehnite (at about 90 feet); analcite and chlorite also occur in amygdules; the amygdules are often but partly filled, and lined with tufted chlorite and with white crystals. Laumonite also occurs.

0 109; Seam of **sedimentary** matter.

21 (20) 109–130; (Ss. 15293–4). **Porphyrite,** amygdaloidal; like the flow above, with alternating bands; more or less conspicuously porphyritic; possibly more than one flow; at 127 feet narrow vein of *copper*, prehnite and quartz.

0 At 130 seam of **sedimentary** matter; much prehnite.

32 (31)	130-162; (Ss. 15295-6). **Porphyrite,** amygdaloidal, as above; at 160 feet seam of *copper* in cubes, prehnite and quartz.
35 (34)	162-197; (Ss. 15297-8). **Melaphyre,** porphyrite.
	197. Flinty-looking epidotic seam, a mass of **brecciated** prehnite and quartz. It will be observed that copper has been noted in four places in the beds immediately above, and that the amygdaloids are quite rich in minerals It seems quite possible that here at 197 feet is the center of the **vein** which has been a channel for this impregnation. There may be a fault here.
2	197-199; (Ss. 15299-300). **Amygdaloid.** See petrographic chapter.
0	199; (S. 15301). Seam of **sedimentary** matter; apparent dip 21°.
11	199-210; (Ss. 15301-3). **Amygdaloid;** much decomposed, with zeolites, etc.
11	210-221; (Ss. 15304-5). **Porphyrite,** amygdaloidal; like the rocks above near 130 feet.
81 (79)	221-302; (Ss. 15306-15) **Melaphyre;** intermediate type, quite feldspathic, yet in traces ophitic, with red feldspathic seams, and like Marvine's bed No. 87, which is one of Irving's types of the "ordinary olivine-free" diabase (Copper-Bearing Rocks, Mon. V., U. S. Geol. Sur., p. 65.)
22 (21)	302-324; (S. 15316). **Amygdaloid.**
0	324; (S. 15317). **Vein** (possibly fault or contact); carries *copper* crystals, prehnite and quartz.
13	324-337. **Amygdaloid.**
0	337; (S. 15319). Vein and perhaps contact; carries *copper*, etc.
(1,948)	
38 (37)	337-375; (Ss. 15318-20). **Porphyrite,** amygdaloidal; fine grained and full of small chloritic amygdules and chloritic seams, which simulate bedding and may mark flow lines. Dip 17° to 18° at 371 feet, 23° at 373 feet.
19	375-394; (Ss. 15320-1). **Porphyrite,** amygdaloidal; analcite in cavities at 375 feet; generally fine grained chloritic amygdules.
29 (28)	394-423; (Ss. 15321-4). **Melaphyre;** intermediate form, more basic than adjacent flows, and somewhat ophitic.
7	423-430. **Amygdaloid.** (It is not certain that S. 15324 does not belong to this flow.) I take this bed to be equivalent to No. VI, 74-81 feet, and we pass from No. VII, 430 feet, to the record of No. VI. While immediately below these points, in No. VII and in No. VI, respectively, there is a very peculiar bed of porphyry and felsite tufa, which makes the correlation a good one, the beds above this bed (i. e., above No. VI, 81 feet and No. VII, 430 feet) do not match very well. This bed of porphyry tufa lies directly over the Greenstone, which

corresponds, as we suppose, to Marvine's beds No. 90–108 at Eagle River. Hence we should be at a point which according to our correlations should correspond to 1117 feet below the "slide" at Marvine's bed No. 63 and 431 feet more or less below the sandstone of Marvine's bed No. 80, while the corresponding thicknesses in our Isle Royale column are about 900 feet and 400 feet (see p. 66), rather greater than we should expect, for the increase in thickness of Keweenaw Point over Isle Royale is generally greater than this indicates.* We are led then to suspect faulting in No. VII, by which the series may have been duplicated. There are a number of places where faulting might occur in No. VII, but we have no means of determining its amount. Such faulting might account for the disparities between drill holes Nos. VI and VII, but the topography does not indicate any such fault, and it is easy to imagine that the Greenstone, which is very much thicker at Eagle River than in these drill holes, was so prominent at the former point that some of the immediately subsequent flows flowed around and did not cover the Eagle River part, while on the other hand they did cover Isle Royale. Mr. Stockly, however, reports a "break" as apparent near No. VII, running nearly south (and thus liable to pass between No. VI and No. VII), and throwing the east side down. Such a fault as that would, if it were a normal fault, hade to the east, and if it passed through the middle of drill hole No. VII, would not disturb the correlations and dips at all, but would cause us to leave out some beds unawares. In No. VII, however, the column as we have seen seems to be exceptionally full, so that we cannot attribute any great effect to the supposed fault. If it did not pass through the bottom of No. VII, and according to its strike it should not, the effect of such a fault would be to make the dip derived from correlations between Nos. VII and VI greater than it really is.

But the dip derived from the correlation No. VII, 430 feet, with No. VI, 81 ft, is (430–81 = 349 feet plus the difference in altitude, 341–263 = 78 feet) 427÷1848, i. e., 0.231 = tan 13°, practically the same dip as found between No. VIII and No. VII. (p. 71.)

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*See preceding pages, and end of this chapter.

DRILL HOLE NO. VI.

Above the correlation line we have—

0-17; (Ss. 15226-8). **Melaphyre;** shows occasional large porphyritic plagioclase crystals; is in general of intermediate type, like No. VII, 221-302 feet.

17-25; (Ss. 15229-30). **Porphyrite,** amygdaloidal; chloritic and laumonitic.

25-59; (Ss. 15231-3). **Porphyrite,** amygdaloidal; with chlorite or laumonite amygdules, white on red ground; occasional large porphyritic plagioclase; tubular amygdules at the bottom of bed.

59-67 or 72: (Ss. 15234-5?). **Porphyrite,** amygdaloidal; very porous: cavities lined with crystals.

72-81; (Ss. 15235-6). **Amygdaloid.** Cavities with fillings of radiating chlorite fibres.

10 81-91; (Ss. 15237-42). **Porphyry Tufa.** At the top there is a bed showing under the microscope the conchoidal forms of glass ashes, but in general the signs of sedimentation are very obscure, so much so that from mere inspection with the unaided eye I could hardly be sure that I was not examining a brecciated porphyry flow with some enclosures. This does not appear like a water-worn conglomerate, but like a contemporaneous tufa. It may be correlated with the "jasper," 67.7 feet above the Allouez conglomerate at the Peninsula mine (Hubbard, Proceedings L. S. Mining Institute, 1894, p. 93), and 460 feet down in Tamarack No. 1 shaft (Geol. Sur. of Mich., Vol. V, Pt. I, p. 112).

33 91-124; (Ss. 15243-7). **Ophite.**

(32)

(2,077)

239 (233) 124-363; (Ss. 15248-58). **Ophite,** the Greenstone. This is the largest single flow that we meet. It makes the "backbone" of the island, extending from Card Point to Blake Point in an almost uninterrupted ridge. Judging from the mottlings which are larger as we go northeast, and from the greater height of the ridge in that direction and from other reasons, the sheet thickens toward the northeast. This bed is distinctly lustre-mottled, and in sharp contrast with the series of porphyrites which overlie it and make a parallel ridge that extends from a low outcrop on the south side of Grace Harbor (including also part of Washington Island, further west), north of the Island mine, Siskowit Lake and Lake Richey, to the east end of Scovill Point. The backbone ridge thus agrees

in every way with the great corresponding ridge on Keweenaw Point, which is included in Marvine's beds of "diorite" (not having the use of the microscope, Marvine mistook augite for hornblende) Nos. 91 to 108, from 2927 feet to 4120 feet of the Eagle River section, which after personal inspection I pronounce a unit, the lighter and darker types being merely differentiations in the same flow. This is a colossal thickness for one flow (1193 feet), but I could find no finer grained band such as would mark a contact. Moreover, if we compare the size of the coarsest mottlings near Eagle River with those of the much thinner (233 feet) section of Isle Royale, some such great thickness is indicated. (See chapter V, on grain.) That we should find it thinner on the island is moreover in harmony with what we have hitherto found. This same Greenstone also thins very much toward the southwest along Keweenaw Point, as shown by Marvine, and by Hubbard (*loc. cit.*, p. 95). Moreover, both on Keweenaw Point and on Isle Royale, we shall find, in the series below it, similarly basic ophites predominating, while on the other hand the porphyrite type which has been so dominant above, from 589 feet to 2035 feet (1446 feet approximately equal to Marvine's 1272–2840, or 1568 feet) occurs only at intervals.

(2,310)

23 363–386; (Ss. 15259–66). **Conglomerate;** at the top a fine grained
(22) "ashbed," with a vesicular texture that appears to be due to
contact with the overlying Greenstone; below 374 feet a more
(2,332) ordinary conglomerate, with acid pebbles of quartz porphyrites
and felsites. There are also basic pebbles in it and the cement
is calcareous. This must, according to our correlations, be
the Allouez conglomerate, or the "slide" conglomerate, No.
15 of Marvine's plate.

We are now beneath the Eagle River section and for our correlations we shall have to use other sections, such as that of the Central mine, and the developments around Calumet.

8 386–394; (Ss. 15268–9). **Melaphyre.** This is a fine grained trap
with no amygdaloidal top. Has it not been planed off by a
fault? It is somewhat porphyritic, but tends to be ophitic at
the center.

54 394–448; (Ss. 15269–72). **Porphyrite,** amygdaloidal; more or less
(53) amygdaloidal for 21 feet at the top and 12 feet at the bottom.
This is really of the intermediate type with a doleritic texture
in the middle.

64 448–512; (Ss. 15273–7). **Melaphyre,** ophite; not a very pro-
(62) nounced type; about 8 feet amygdaloidal with calcite veins;
feldspathic; slight mottling. At this bed we probably pass
(2,455) over to the record of hole No. II.

DRILL HOLE NO. II.

As no conglomerate appears in drill hole No. II, its top bed, an ophite, must find its correlate at or below No. VI, 386 feet. Hence No. II must find for its first belt of amygdaloid, which occurs from 57 feet to 58 feet, a match in No. VI, not above 450 feet. The first such match is at No. VI, 512 feet, which we have adopted, since that will give us in each drill hole a heavy ophite above and a smaller one below. But if we compute the dip from this correlation, subtracting 512 feet in No. VI from 57 feet in No. II gives a difference of 455 feet. Adding the excess of altitude of No. II over No. VI (407 feet—341 feet), i. e., 66 feet, we have 521 feet, which divided by 2406 is 0.216, equal to tan 12° 10′. Thus we find too flat a dip, nearly a degree flatter than the last computation. If the dip were the same as previously (13°) or even steeper, drill hole No. II, 0 feet, would find its correlate at No. VI, 489 feet, or lower, but to say nothing of the fact that the beds in this case would not match as well, observations at the surface show that No. II is close to the top of the Greenstone or "backbone" ridge and cannot be very much below the great ophite, No. VI, 124-363 feet, which forms it. This of course favors as high a correlation in No. VI as we can get. The extra flat dip would then be due to a fault throwing No. VI up, but whether the fault strikes with the strike of the beds, and produces the ridge on which No. VI stands, or runs north, throwing the east side to the south, as analogy would render likely, or runs to the east, throwing the south side up and to the west, is not certain. It might pass through No. VI, near 393 feet. The upthrow, if 13° is the true dip, would be 34 feet.

0-57; (Ss. 15067-9). **Melaphyre,** ophite; rather feldspathic; in the exposures around the drill holes there are agate and laumonite amygdules.

7 57-64; (Ss. 15070-1). **Melaphyre;** fine grained, but of ophite type equivalent to No. VI, 512-523 feet, which may be more than one flow.

72 64-136; (Ss. 15072-5). **Melaphyre,** ophite.
(70)

0 136; (S. 15075). **Sedimentary** seam.
(2,532)

39 136-175; (Ss. 15075-9). **Amygdaloid** or **Conglomerate.** The
(38) samples of this bed were but scant as it is described as very
(2,570) rotten, and much of it was lost. At 167 feet a clay seam was
noted. The samples are not sufficient to determine surely

whether we are dealing with an amygdaloid full of sandstone
seams, or with a fault, or with a scoriaceous conglomerate.
Possibly the Houghton conglomerate?

39 175–214; (Ss. 15080–2). **Melaphyre,** ophite. There is some doubt
(38) whether this is not one flow with the underlying.

57 214–271; (Ss. 15083–5). **Melaphyre,** ophite; about 9 feet coarsely
(56) amygdaloidal at the top, and 1 foot at the bottom.

54 271–325; (Ss. 15086–7). **Melaphyre,** ophite; about 14 feet amyg-
(53) daloidal at top; at 315 feet and 320 feet, seams of decomposition,
and then more amygdaloidal to bottom; carries laumonite and
calcite.

40 325–365; (Ss. 15087–8). **Amygdaloids;** probably more flows than
(39) one; base ill-defined.

73 365–438; (Ss. 15089–91). **Melaphyre,** ophite; amygdaloidal at
(71) top, grey, and apparently not very basic.

37 438–475; (Ss. 15092–4). **Amygdaloids,** brecciated; very soft, so
(36) that we have only 17 feet of core for 38 feet of boring, probably
a number of beds and possibly a fault. (Houghton conglom-
erate?)

81 475–556; (Ss. 15095–7). **Melaphyre,** ophite; top and bottom quite
(79) uncertain, but the massive mottled center is quite distinct; at
(2,942) about 554 feet becomes much veined, disintegrated, and preh-
nitic, with some *copper*.

14 556–570; (Ss. 15098–9). **Amygdaloid,** brecciated.

30 570–600 (?). **Melaphyre,** ophite (?); amygdaloidal; core about
(29) half ground away.

31 600–631; (Ss. 15100–1). **Melaphyre,** ophite.
(30)

19 631–650; (S. 15102). **Amygdaloid;** at 650 feet very much ground
away and decomposed; a chance for a slide. Below this point
(3,034) No. II shows a massive, distinctly mottled ophite, all the way
down (chlorite vein from 697 feet down to 700 feet), so coarse
at the bottom that it is evidently considerably thicker, upwards
of 70 feet thick. If this is repeated above, it must be either at
64 feet (the beds above 64 feet are too massive) or at 365 feet,
which is possible, though there are reasons brought out by the
microscope for believing this also not to be the case; moreover,
the beds above do not harmonize. While there are several
disturbed zones in No. II, there is no pressing reason, micro-
scopic or otherwise, for supposing that a repetition in the
series is shown.

When we turn to drill hole No. IV, we find a similar melaphyre at the very top. If we let No. II, 683 feet, be equivalent to No. IV, 0 feet (using the similar grain of the rock as an indication that the two samples have similar positions in the flow), we have for the dip the difference, 683 feet, minus the difference of altitude (407-194 feet), 213 feet = 470 feet, which divided by 1808 feet is 0.260, i. e., tan 14° 30′. Thus, either the dip has become steeper or the correlation should be higher up in hole No. II, or a fault separates No. II and No. IV, such that No. IV is thrown up. This last supposition I deem most likely, for there is a ravine just to the east of No. IV, through which such a fault, running north and south, might go. Moreover, tunnels No. II and III do not strike the same rock, as would otherwise be expected; the one is east and the other west of this supposed break. Drill holes Nos. V and II are about in the direction of dip from each other and the fault suggested would also throw up No. IV relative to No. V, which is what the topography and records suggest.

Tunnel No. VII is in ophite, with seams, red, white, clayey and chloritic, which may be matched anywhere along the middle of hole No. II, and do not throw much light on the correlations. Supposing the dip to be 13°, as it has been taken to be to the south, the corresponding up-throw of No. IV would be 52 feet.

DRILL HOLE NO. IV.

	33	From No. II. 650 feet (Ss. 15103-7).
	(32)	
	40	to No. IV, 40 feet (Ss. 15155-7). **Melaphyre,** ophite.
	(39)	
(71)		
68		40-108; (Ss. 15158-60). **Melaphyre,** ophite; about 9 feet of amygdaloid at top, with calcite and chlorite.
(66)		
0		108: (S. 15161). **Sediment,** basic; to the naked eye like a fine grained amygdaloid.
25		108-133; (Ss. 15162-3). **Melaphyre,** ophite; fine grained; at 122 feet, fissure with quartz crystals.
(24)		
2		133-135; (S. 15164). **Sandstone,** basic; the Calumet conglomerate (No. 13 of Marvine's table, opp. p. 60) should come about here. As the top of the bed below does not begin in an amygdaloidal streak, but is quite coarse, we must infer an erosion or a slide at this point.
(3,197)		
92		135-227; (Ss. 15165-8). **Melaphyre,** ophite; very ferruginous.
(90)		
	18	227-245; (Ss. 15168-9). **Amygdaloid,** brecciated.
	18	245-263: (Ss. 15170-1). **Amygdaloid.**

17 263–280; (S. 15172). **Amygdaloid.**
24 280–304; (S. 15173). **Amygdaloid.**
(23)
(75) The above series of amygdaloids are very much alike, very soft,
(3.363) veined, red, and so much ground away that only about half the
core was left; consequently the limits of the various flows are
very uncertain. Prehnite also occurs in them.

120 304–424; (Ss. 15174–83). **Melaphyre,** ophite.
(117)
(3,480) **Clay** seam at 313 feet, near which the rock is much decomposed,
fissured and seamed.

10 424–434; (Ss. 15184–6). **Amygdaloid,** chloritic and laumonitic.
16 434–450; (Ss. 15187–8). **Amygdaloid;** porphyritic texture, which
is common in the other amygdaloids, with *copper*, laumonite
(3,506) and prehnite.

156 450–605½; (Ss. 15189–96). **Melaphyre,** ophite; very feldspathic;
(152) the bottom of bed not reached at the end of the hole, but the grain has become finer there, indicating that we are more than half way through the bed and not more than about 18 feet from the foot. With this flow we pass to drill hole No. V, and the latter must overlap unless the dip is 20°, or unless there is a fault of about 150 feet. With a dip of 13° we should expect to find No. V, 0 feet, at No. IV, 436 feet; if the dip is 14°, then at No. IV, 462 feet, etc. But the ophites around the top of No. V are, judging either from their thickness as measured in the section, which might be affected by the numerous seams in No. V, or from the coarseness of grain, not as thick as the bottom flow in No. IV. Nor are they quite as feldspathic. The bottom of No. V, though it lies in a fissure, and the record cannot be made out clearly, is in coarse feldspathic ophite, which corresponds both to the bottom of No. IV and also to the top of No. I. Drill hole No. I lies on the northwest side of a ridge which rises from Washington River, and is composed of ophites like the Greenstone. No. I is 30 feet lower than No. IV and 2092 feet + 1293 feet, i. e., 3385 feet from it to the northwest, at right angles to the strike. Thus at 14° dip the top of No. I would be (846+30, = 876 feet below the top of No. IV, at 13° dip (782+30) 812 feet below it. Thus there would be a gap of something over 200 feet between the bottom of No. IV and the top of No. I. But as No. IV ends in a coarse ophite and No. I begins in one, and as field observations show all the intervening rocks to be coarse ophite, and as drill hole No. V is altogether in the same, we may be sure that the apparent intervening gap, if any there be, is composed of ophite. But it is doubtful if there be really any such gap. The topography

of the Island conforms in general closely to its geological structure, and the thick ophite of the bottom of No. II could hardly fail to make a ridge. There is a ridge, the only one with which it might be correlated, and No. I is directly under the northwest side of it. Again, in No. V the only ophite equally coarse in just above 344 feet, and if we assume No. IV, 610 feet, to correspond to No. V, 344 feet, the difference in level in the geological column would be (610 — 344 = 266, minus the difference in altitudes, 194 — 56 = 138) only 128 feet, whereas if the dip is 14°, there should be a difference of level of (1293 × 0.2493) 324 feet, indicating an up-throw of No. IV of (196 feet) about 200 feet. If the same amount of up-throw existed between No. I and No. IV, the gap in the record between them would be practically wiped away, leaving room for not more than one large ophite flow, which might be the one which occurs at and above the top of No. I and at the bottom of No. V. Since No. V and No. I are 2092 feet apart, at right angles to the strike, and No. V is 108 feet the lower, the top of No. I, with dip = 13°, would correspond to (483-108) 375 feet, or with dip = 14°, to (523-108) 415 feet, in No. V, and the two holes would barely overlap. This is probable, as the bottom of No. V and the top of No. I are very similar; so that if not exactly the same horizon, they are probably from the same flow. If we can consider them identical, we can also assume that the top of No. I makes a continuous record with No. IV. (No. IV, 606 feet = No. I, 0 feet.) This seems on the whole the best plan, as drill hole No. V crosses and recrosses a fissure and there is no guarantee that the different parts of it are in any fixed relation to each other. But at the same time we must remember that in thus allowing about 270 feet of upthrow,[*] we may be shortening our column too much, but we may be reasonably confident that the beds we may have thus omitted are two or three large flows of ophite. There are certain reasons which make a fault of the nature we have described probable. We have already spoken (p. 78) of the probability that No. IV is thrown up, and the line of strike of the fault may be marked by the Washington harbor depression. (See also p. 60.)

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[*] 3385 feet x 0.25 (tan 14°, about the dip which Stockly determined in this locality) = 846 feet. From this subtract difference of level of corresponding points, 606 feet, less difference in altitude, 194 — 163.7 or 30 feet, = 576 feet. 846 — 576 = 270.

DRILL HOLE NO. V.

We give the record of No. V, though it will not be included in our general column.

0–104; (Ss. 15197–203). **Melaphyre,** ophite; veined, decomposed and laumonitic: at 18 feet about 2 feet of brecciated vein matter, with white and chloritic seams in the neighboring rock.

105; (S. 15205). "Slide" rock, fine grained.

130. A similar belt.

150–152. Thoroughly decomposed; vein.

188. A thin *fissure;* a red, calcareous, decomposed belt, very prehnitic; probably also a contact of flows.

105–188; (Ss. 15205–10). **Melaphyre,** ophite; coarsest near 163 feet.

188–210; (Ss. 15210–3). **Melaphyre,** ophite; first five feet amygdaloidal; feldspathic; mottling not prominent.

210. **Clay** seam.

231. Finer grained.

210–343; (Ss. 15214–9). **Melaphyre,** ophite. Feldspathic, mottling not prominent, but rather a diabasic texture of feldspar laths; occasional amygdules, seams and veins; toward the bottom the mottling becomes more marked.

343. Enter *fissure;* rock much decomposed, fine grained and prehnitic.

344. **Clay** seam.

346; (S. 15220). **Amygdaloid,** not far from contact; feldspathic.

365. Leave fissure, i. e., the amygdaloidal zone.

344–376. Perhaps one small **Melaphyre,** ophite.

375. Cross fissure (?).

376–415. **Melaphyre,** ophite; amygdaloidal at top.

397. Cross fissure again (?). End of drill hole No. V.

DRILL HOLE NO. I.

Hereafter, in reducing from **vertical** *depth along drill hole to* **thickness,** *1-30 is taken off.*

No. I, 0 feet, taken as equivalent to No. IV, 606 feet.

(3,656) This corresponds very nearly to a dip of 14° 20′, which is what
we have by correlation of No. I and No. III, p. 84.

63 0–63; (Ss. 15001–4). **Melaphyre,** ophite; mottled feldspathic and
(61) slightly amygdaloidal.

90 63–153; (Ss. 15005–10). **Melaphyre,** ophite; amygdaloidal at top;
(87) darker, black, and mottled at bottom. *Copper* and prehnite
seam, and spangles of *copper* on chloritic joints.

74 (72) 153-227: (Ss. 15011-6). **Melaphyre,** ophite: amygdaloidal the first 10 feet, which character fades out in the next 9 feet: chlorite and calcite amygdules and veins.

48 (46) 227-275: (Ss. 15017-20). **Melaphyre,** ophite; 5 feet of amygdaloid at top, with a little *copper.*

23 (22) 275-298; (Ss. 15021-5). **Melaphyre;** fine grained, somewhat ophitic, amygdaloidal for 4 feet at top and 3 feet at bottom; with prehnite, calcite and laumonite.

64 (62) 298-362; (Ss. 15026-37). **Melaphyre,** ophite: amygdaloidal for about 10 feet at the top, with chlorite and a little *copper;* at 316 feet vein of datolite (?) and *copper*, and at 321 feet *copper* again. It is equivalent to the flow, from the top of No. III down to 44 feet, which is also a veined ophite with a seam containing *copper*, at 19 feet.

At the very bottom of the bed are some tubular amygdules running lengthwise of the drill cores, i. e., perpendicular to the contact, which contain some calcite, chlorite and *copper.*

15 362-377; (Ss. 15038-9). **Melaphyre,** amygdaloidal. Equivalent in drill hole No. III to 44-59 feet.

9 377-386; (Ss. 15040-1). **Melaphyre,** amygdaloidal. Equivalent in drill hole No. III to 59-67 feet.

39 (38) 386-426: (Ss. 15041-5). Fine grained amygdaloids and scoriaceous beds with basic sediment mixed and at the bottom. This is equivalent to the beds No. III, 67-110 feet, but the trap and sediment being both fine grained, it is difficult to separate them. We may be sure of having quite a marked scoriaceous **conglomerate** here. There is a noteworthy amount of the felsitic debris, the first such occurrence under the Allouez conglomerate, No. VI, 363 feet, and there are also agate pebbles.

I take this to be the Kearsarge conglomerate, for reasons mentioned below in connection with the Minong porphyrite.

30 (29) (4,097) 426-456: (Ss. 15045-50). Minong **Porphyrite;** equivalent to No. III, 100-134 feet. This is quite acid, probably not belonging to the melaphyres at all, but rather a felsite porphyrite. No olivine can be recognized in it with certainty, either microscopically or otherwise. The character is more distinct under the microscope, but the extreme fineness of grain, the scoriaceous porous and brecciated appearance, peculiar in that the pores are fine and irregular, can be recognized. We shall call this the Minong porphyrite. Elsewhere it appears to be distinctly a felsite porphyrite, but the unaided eye could hardly distinguish it as such in the drill cores. Now we find under the lowest conglomerate in the Central mine, which Hubbard has correlated with the Kearsarge (Proc. L. S. M. I., Vol. III, 1895, p. 75) a trap which appears to be of similarly acid

character, and I know of none such higher in the series, either on Isle Royale or in the Central mine, that is below the Allouez conglomerate. Now as to relative position, the Kearsarge conglomerate varies from 2,599 feet below the Allouez at the Central mine to 2,239 feet at Calumet. According to our reckoning, on Isle Royale it is (4.068-2,332 feet) 1,736 feet. This is not far from two-thirds the thickness of the intervening beds at the Central mine, and we may remember that on page 68 we found the ratio of the distances between Marvine's No. 43 and No. 65 to be $\frac{396}{578}$, very much the same. As to its relations with other conglomerates, the distance between the Kearsarge conglomerate, Marvine's No. 11, and the Allouez conglomerate, his No. 15, is about cut in two by the Calumet conglomerate, No. 13, and we have at 3,197 feet (i. e., No. IV, 133 feet) a basic sandstone, which may represent it, or this may be the North Star conglomerate, No. 12, and the Calumet conglomerate may be represented by the sediment 24 feet higher in the series. At any rate the period of slackened eruptive activity in that portion of the series is marked.

Then nearer the Allouez conglomerate than the Calumet is the Houghton conglomerate, No. 14, and of that we find traces at 2,532 feet. These two intermediate beds, the Calumet and the Houghton conglomerates, are much thinner and more basic in character than along Keweenaw Point,* but that is what we should expect from the general thinning out of all the rocks. The correlation is then fairly satisfactory, and the more so, because in constructing our column (p. 80) we have, between drill holes No. IV and No. I, allowed for 270 feet of faulting, of which we were by no means sure. That our correlations come out thus well, strengthens us in our confidence that we were right in allowing for that fault.

80 (77) 456-536; (Ss. 15051-5). **Melaphyre,** porphyrite, the "Minong trap;" equivalent to No. III, 135-415 feet. It is sometimes faintly mottled toward the lower third of its thickness, but in general it is much finer grained for its size than the ophites. It is compact and has a clean conchoidal fracture, and tends to basaltic jointing. Occasional fair-sized carnelian agates are a feature of this bed. On the other hand it differs from the porphyrites above the Greenstone aside from microscopic characters by being much darker—black, rather than grayish green. It can be traced almost continuously the full length of the island, from a projecting point on the north line of Sec. 35, T. 64, R. 39, through the Wendigo property, where the trail running from Sec. 20 to Sec. 15 (Pl. III) is nearly

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* See later part of this volume, where the Houghton conglomerate in the Peninsula mine is shown to be very basic in its lower half.

along its outcrop. Its lower contact was opened up by numerous costeans on the northwest side and by tunnel No. 5. It runs along the south side of Todd Harbor, where it was again developed by costeans (I and II), and at McCulloch's mine (p. 5). Passing near the west quarter post of Sec. 27, T. 66, R. 35, it formed the foot of the more extensive workings of the Minong mine (though there was also some test-pitting under it), and thence may be followed to the north side of Locke Point.

At the bottom of this flow we pass from the record of drill hole No. I to that of No. III. No. I, 536 feet, is No. III, 215 feet., i. e., 321 feet higher. Adding the excess of elevation of No. III over No. I (231 — 164 = 67 feet), we have 388 feet difference in level, which divided by 1,518 feet, the distance between the two holes in the direction of the cross-section, gives a dip of 14° 20′. This is the most accurately determined dip that we have, and we get the same result by supposing that the bottom of No. V just laps the top of No. I, and we shall also get the same result by correlating No. III and No. XIII. Stockly's observations, using the outcrop at the surface near tunnel No. 5, made the dip a little less (14¼°), but only a fraction of a degree. There is no indication of a fault either wav between No. I and No. III, and there is no possibility of much of a fault. (4,174)

DRILL HOLE NO. III.

94 215–309; (Ss. 15123–8). **Melaphyre,** ophite; equivalent to No. I,
(91) 536–630 feet (Ss. 15056–61); quite amygdaloidal at top, with
traces of a sedimentary parting.

0 309; (S. 15129). Sediment, i. e., **Shale;** mainly composed of
plagioclase feldspar, but there is some quartz in it; cf. No. I,
(4,265) 630 feet; may perhaps be two or three feet thick.

30 309–339; (Ss. 15130–3). **Melaphyre,** amygdaloidal. Veined and
(29) seamed; very feldspathic; corresponds to No. I, 630–662 feet.
(S. 15064).

24 339–363; (S. 15134). **Melaphyre,** amygdaloidal; drill hole No. I
(23) extends down to 700 feet, but is much decomposed in the lowest
(4,317) part, and the beds there are not easily separable.

47 363–410; (Ss. 15135–8). **Ophite,** amygdaloidal; possibly two flows,
(45) separated at 380 feet.

43 410–453; (Ss. 15139–42). **Melaphyre,** ophite.
(42)

20 453–473; (Ss. 15143–4). **Melaphyre,** feldspathic.
(19)

89 473–562; (Ss. 15145–51). **Melaphyre,** ophite; at 497 feet the drill-
(86) ers are said to have struck a vein and to have followed it for
(4,509) 82 feet. S. 15149 at 496 feet and S. 15150 at 545 feet show a
prehnite and calcite vein with crystallized *copper*.

DRILL HOLE NO. XIII.

At this point it seems best to pass to drill hole No. XIII, whose beginning is in a band of very chloritic amygdaloid close to the north of some bluffs of ophite. Two holes were put down here, one vertical and the other, No. XIIIA, at an angle of 45° to the east. Drill hole No. XIII is somewhat farther from tunnel No. 5, which is in the foot of the Minong trap (drill hole No. I, 536 feet = No. III, 215 feet), than the tunnel is from drill hole No. I. The distance from No. III to No. XIII is 1775 feet and the top of No. III is (231–216) 15 feet the lower. Hence, allowing the dip slope to be 1:4 (tan 14½°) the top of No. XIII, in the absence of faults, would correspond to No. III, 459 feet. The first samples of the vertical hole No. XIII were accidentally mixed from 31 feet to 113 feet, so that we shall have to use the record of No. XIIIA for this part of our section. In hole No. XIII the rock grows less amygdaloidal after the first 17 feet and in hole No. XIIIA after the first 35 feet (v. 25),* then the hole passes into a uniform looking gray ophite which begins to be finer grained about 79 feet (v. 56 feet), but we do not reach its bottom, for at 86 feet (v. 61 feet), we cross a fissure, then, at 132 feet (v. 93 feet), come to a marked contact of two quite amygdaloidal flows, with *copper* and prehnite in the amygdules. From this point the rock is once more a massive ophite down to 208 feet (v. 147 feet), where there is another contact, with a band of basic sandstone. In No. XIII we have no distinct record until after 113 feet; then we meet a contact with a little sandstone at 125 feet. After this the rock is coarse grained down to 166 feet, when it becomes finer and grows amygdaloidal with vertical clay seams, down to 240 feet. At 230 feet we find a foot of sandstone like that at 125 feet. There are petrographic reasons, in the nature of the feldspar in the adjoining flows, for thinking that No. XIIIA (v. 93 feet) corresponds to No. XIII, 125 feet. If we suppose, as indicated by the dip, that the amygdaloid at the top of No. XIII is that which occurs in No. III, 453 feet, then the first 17 to 25 feet of amygdaloidal rock will correspond to a point in No. III, down about 473 feet. Then for the bottom contact of the big ophite next below, at No. III, 562 feet, our first match will be No. XIII, 125 feet, and No. XIIIA (v. 93 feet). If we compute the dips from these correlations, we find that we have 562-125 + difference in altitude (216-231) is 422, divided by distance at right angles to strike, from No. XIII to No. III, 1,775 feet, is 0.238, or tan 13° 20′: 562-93 + difference in altitude (216-231) is 454, divided by distance at right angles to strike, from No. XIII to No. III, 1.775 feet, is 0.256, or tan 14° 20′.

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* The numbers referring to XIIIA with a v. before them are the distances reduced to the vertical by multiplying by sin. 45°, i. e., 0.7071.

It is not likely that the dip is becoming flatter as we go northwest from this point, for in general it grows steeper in that direction, and the dip about No. III was determined (p. 84) with the aid of No. 5 tunnel, as 14° 15′. It is therefore probable that the lower part of No. XIIIA is more nearly in undisturbed relations with No. III, 562 feet, than is No. XIII, though the dip may be steeper than thus indicated. Then the fault which cuts No. XIIIA at 86 feet must separate No. III, 562 feet, from No. XIII, 125 feet. It has an upthrow of (125-93) 32 feet, and in that case the amygdaloid at the top of No. XIII should correspond to No: III, 437 feet, but this is not a good correlation at all. The correlation found by assuming that the ground between the top of No. XIII and No. III is undisturbed, i. e., that (1775 × 0.256 = 454 + 15) No. XIII, 0 feet, is equivalent to No. III, 468 feet, is much better. If we accept this correlation, we must imagine that the fissure vein which crossed No. XIIIA crosses No. III also, probably being the vein entering at No. III, 497 feet, and throwing the part above up. Now drill holes Nos. XII, XIV, XIII, tunnel No. 5 and drill holes Nos. III and I, were all located near a supposed fault or vein which is indicated by a topographic break that runs a little east of north. A vein in about this position was indicated on Hill's map, 1871. Now such a fault, if a normal fault with a hade slightly to the west, is just the one to have done the work we have attributed to it, passing a little to the east of No. XIII and No. III, but cutting into No. III at 497 feet. Figure 11 illustrates it, looking in the direction of the strike of the rocks. Now, there is a fissure that comes into No. XIII at about 252 feet or a little higher, and it will be interesting to compute what the dip of the fault would be if the latter were a continuation of the former. Of course, too much stress should not be laid on this computation, because fissures are irregular, and because inclined drill holes are very liable to go astray. But supposing that all is right, we find (Fig. 11) the following results:

Using a projection plane this time in the direction of the strike, that is, imagine we are looking northwest. From A draw AD, representing hole No. XIII, and at 45° AB, representing hole No. XIIIA. Let B be the point where the fault cuts hole No. XIIIA (86 feet), and C a point at the same level in No. XIII (86 × tan 45°, i. e., 61 feet). CB is also 61 feet. Let D be the point where the fault is supposed to cut No. XIII (252 feet). Then CD is 191 feet and the tan ∠CDB is CB/CD, i. e., $\frac{61}{191}$. Now in the stereographic projection around C the direction of dip of beds is foreshortened to C, and the strike of the fault foreshortened to CN. If we draw CF from C parallel to BD, CFN will represent the fault. The dip of the fault will be ∠CNF. CN will represent the difference between the direction of dip of the beds and the direction of strike of the faults, say 35°, and ∠FCN is 90° plus ∠FCD, which latter is equal to the angle ∠CDB. Finally CF is 90°, so that we have only to deal with right spherical triangles, and we have the simple formula—

$$\tan \angle CNF \text{ (the dip of fault)} = \tan NCF \times \sec CN$$
$$= \frac{1.22}{\tan \angle CDB,\ \text{i. e., } \frac{61}{191}.}$$

which gives us tan dip = 3.8, i. e., dip of fault is 75°.

A dip of 75°, which brings the fault nearly perpendicular to the bedding, is not beyond the range of probability. It is then quite likely that this fault has cut 31 feet out of the thickness of the ophite No. III, 473–562, and a corresponding amount out of No. III near No. XIII, 252 feet. Following our general rule, however, that we shall make the series as short as possible, we shall make no additions for this in our geological column.

The record of drill hole No. XIII is then as follows:

DRILL HOLE NO. XIII.

(4,509)

1 125–126; (S. 15722). **Sandstone,** basic and red.

58 (56) 126–184; (Ss. 15723–41). **Melaphyre,** ophite.

45 (43) 184–229; (Ss. 15742–5). **Melaphyre,** feldspathic ophite.

1 229–230; (S. 15746). **Sandstone,** basic, associated with clay veins running into hanging and foot. This or the bed at 125 feet may represent Marvine's slaty sandstone, No. 9; at least either of them is in about the right position for it, if the Minong conglomerate is the same as the Kearsarge conglomerate—4509 respectively 4611, minus 4068 = 441 feet respectively 543 feet below. But this is only a suggestion.

22 230–252; (Ss. 15747–51). **Melaphyre,** amygdaloidal, fine grained;
(21) red, with clay veins from the top and the bottom; brecciated
and prehnitic. Seems to be of the porphyrite type.

90 252–342; (Ss. 15752–61). **Melaphyre,** ophite; feldspathic.
(87)

7 342–349; (Ss. 15761–2). **Melaphyre,** amygdaloidal.

10 349–359. (S. 15763). **Melaphyre,** amygdaloidal; prehnitic.

(4,735)

88.5 359–447.5; (Ss. 15764–72). **Melaphyre,** ophite; amygdaloidal for
(86) the first 8 or 9 feet.

447.5–503; (Ss. 15773–9). **Melaphyre,** porphyrite; has a peculiar character microscopically, which we find again in the bed at the top of No. XIV; red; fine grained; laumonitic, with chlorite and calcite; very feldspathic, with little augite visible, even under the microscope.

With this bed we pass to the record of drill hole No. XIV. If we compute where, in No. XIII, the top bed of No. XIV would be, with the dip that we have hitherto used, we find that it would correspond to No. XIII, 406 feet (distance along dip 1,518 feet × tan 14° 20′, i. e. 0.256 = 388 feet, to which add difference of altitude of No. XIV and No. XIII, 216–198 feet, = 18 feet, making in all 406 feet), right in the middle of a big ophite, whereas as a matter of fact the top of No. XIV lies under and to the north of an ophite bluff, and begins in beds like those at the bottom of No. XIII, as already stated. There is therefore little doubt that the top of No. XIV corresponds to beds near the bottom of No. XIII, while the exact correlation is uncertain, the range being between No. XIII, 503 feet, No. XIV, 11 feet, and No. XIII, 448 feet, No. XIV, 11 feet, the correlation may possibly be No. XIII, 493 feet, to No. XIV, 22 feet, an intermediate and otherwise most plausible correlation. Then we shall have (471 feet — 18 feet) 453 feet for the difference in level of corresponding beds or (453 divided by 1518 = 0.300) a dip of 16° 40′ here. If this steeper dip were due to a fault, it would mean that No. XIV was on the up-throw side, and the bottom of No. XIII on the down-throw side, but there is no reason to think that there is any fault and every reason to believe that this is the true dip, normally increasing. *Consequently for No. XIV we use the factor 0.0438, to reduce from* **vertical** *width along hole to true* **thickness.**

For the next flow we have, from No. XIII, 447.5 to 493 feet,
45.5 already given, 45.5 feet, lapping over on the first 22 feet of
(44) No. XIV.

(4,865)

DRILL HOLE NO. XIV.

116 22–138; (Ss. 15780-9). **Melaphyre,** porphyrite; the last 10 feet of
(111) No. XIII are equivalent to this; at 30–33 feet a seam of
prehnite with numerous *copper* crystals; at 90 feet and again
at 123 feet a chloritic seam with *copper* and calcite.

61 139–200; (Ss. 15790–7). **Melaphyre,** ophite; feldspathic, first 9
(58) feet amygdaloidal; toward the bottom, veins with prehnite
and *copper*.

2 200–202; (S. 15798). **Sandstone,** basic; with amygdaloidal fragments.
This is hardly in the right place for Marvine's
conglomerate No. 8, though we are coming near to its position.

165 202–367; (Ss. 15799-810). **Melaphyre,** ophite; amygdaloidal the
(159) first 9 feet; seamed near 299 feet; a typical coarse ophite which
helps to form the northwest front of the island.

69 367–436; (Ss. 15811–8). The Huginnin porphyrite. This very
(67) marked and peculiar bed has a fine grained red groundmass,
in which are large crystals of whitish feldspar, frequently
about a fifth to a half of an inch long. It is not
uniformly amygdaloidal, but has streaks of half-filled vesicles
with chlorite and *copper* and prehnite and *copper* veins. It has
distinct lines of flow and the upper 10 feet may be an independent
flow. The prehnite and *copper* veins and laumonite
seams occur throughout the bed to the bottom. This porphyrite
outcrops in the bed of Huginnin Creek about 50 feet
from the shore of Huginnin Cove and about 200 feet from the
mouth of the creek; whence its name. Lying, as it does,
between two more resistant big sheets of ophite, and having a
sediment under it, but little is seen of it in spite of its very
peculiar and easily marked character. There is no flow like
it in the whole series. We do, however, catch another glimpse
of it near the mouth of McCargoe Cove, about 500 paces north
and 1,300 paces west of the southeast corner of Sec. 13, T. 66,
R. 35, where it occurs with a similar environment. It seems
to have caught Foster and Whitney's eyes.

4 436–440; (Ss. 15819-20). **Ash,** brecciated. The microscope shows
(5,264) conchoidal glass forms in this rock.

165 440–605; (Ss. 15821-34). **Melaphyre,** ophite. This big flow rivals
(158) the "backbone" greenstone. It appears to have more iron
than the latter. It is so much finer grained toward the bottom
of the hole that we must infer that there are not more than
10 feet more of it. This big ophite being beneath the porphyrite
(5,423) at Huginnin Cove, will be expected to make the front
range of the northwest coast. Now along this coast three

holes were put down, Nos. XII, XV and XVI. They are all about on the same line of strike, No. XV about 10 feet lower than No. XVI and No. XII about half-way between them in position. The samples from No. XII were thrown into confusion by fire, but we have a few that are well authenticated, from the bottom beds and from some other characteristic beds, and we have Stockly's record.

We find in the field that drill hole No. XV lies on the east or upthrown side of the fault already mentioned, No. XVI on the west; No. XII lies very near the break, but apparently also to the east of it. On comparing records, however, we find that No. XII is much more nearly in accord with No. XVI, at least in the lower part, indicating either that the fault is east of that part of No. XII or that the character of the upthrow has changed. Field observations above No. XV show a series of amygdaloids capped by an ophite under which we get a good contact, and a dip 18° to N. 26° W. This contact is about 87 feet above the lake, on a slope whose angle is 28°, while No. XV is only a little above the lake and close to it.

The following sketch (Fig. 12) shows the section at No. XV, and shows that the top of No. XV appears to be something over 100 feet lower than the big ophite at the bottom of No. XIV. Attacking the problem in another way, we find that if the dip remained 16° 40′, the beds at the lake shore (1,300 feet × 0.300 = 390 feet + the altitude of No. XIV, 198 feet) would correspond to No. XIV, 588 feet, which is right in the middle of the big ophite; they are evidently below it. Taking, however, a dip of 18°, a field observation which was on a very good exposure of the under contact of the big ophite aforesaid (Fig. 12), we find (1,300 × 0.325 + 198 feet) that the beds at the lake shore would correspond to No. XIV, 620 feet, which would thus bring the drill holes, if not displaced by faulting, directly beneath the ophite. This is the position occupied by No. XVI, which according to the testimony of the conglomerates that we meet in it begins about 50 feet or more higher up in the series than No. XV. If, therefore, we suppose that the record of No. XVI begins where that of No. XIV leaves off, we shall be in harmony with the observed dips, and not be in danger of leaving out more than some (100 feet — 50 feet) 50 feet of amygdaloids such as are exposed above the mouth of No. XV. It should be said, however, that the nearer the top we compare No. XV and No. XVI the less faulting there seems to be between them. But the records of their upper parts are not very clear, and I fear the samples were not carefully arranged in the boxes.

There is another difficulty and uncertainty attending the construction of this end of our column. We have seen that the dip seems to be increasing faster and faster. Now we have no outcrops nor drill holes farther to the north to guide us as to the rate at which this increase progresses as we go down or to the north, and consequently the amount of allowance for reduction from vertical width to thickness is much more uncertain. We have to guide us a number of dips measured on drill cores which, as we have seen, are not very safe guides, and also we have the dips as exposed on Amygdaloid Island, and on adjacent islands, toward the other end of Isle Royale, which correspond to these lower beds. Both these dips and the dips on the drill cores agree in indicating an increase over the dips observed higher in the series, i. e., toward the southeast. In such case the allowance for dip, and the dip assumed, are matters of general judgment rather than of precise calculation. I have recorded the dips observed on the drill cores. We will continue to assume the 18° dip down to the first conglomerate at No. XVI, 437 feet, *which involves taking off 1-20 to reduce from* **vertical** *width to* **thickness**.

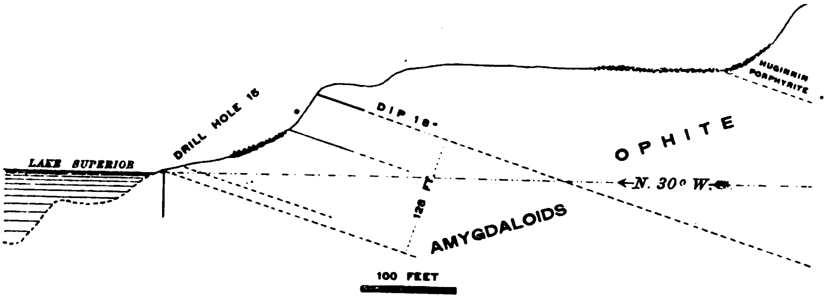

Fig. 12

Cross-section near drill hole No. XV.

We will base our description here on the record of No. XVI, as it is the deepest hole from which we have a full set of cores, and then give Stockly's record of No. XII and a summary of that of No. XV.

DRILL HOLE NO. XVI.

39 0–39; (Ss. 15835–7). **Melaphyre,** ophite; chloritic amygdules at
(38) top of bed.
15 39–54; (Ss. 15838–40). **Melaphyre;** streak of green prehnitic
(14) amygdaloid at top.

27 54–81; (Ss. 15840–2). **Melaphyre;** red and amygdaloidal for the
(26) first 6 to 8 feet, with calcite and laumonite (?) in amygdules.

33 81–114; (Ss. 15843–7). **Melaphyre,** amygdaloidal; at the top the
(31) bed is a green prehnitic amygdaloid like that at 39 feet, which
I suppose to crop out under the lake. From 88–99 feet it is
5,532 much broken and shattered and appears amygdaloidal.

40 114–153.5; (Ss. 15848–50). **Melaphyre,** feldspathic; intermediate
(38) between porphyrite and ophite.

11 153.5–165; (Ss. 15851–3). **Melaphyre,** amygdaloidal; at the top
(11) there is a green decomposed seam; laumonitic amygdules.

9 165–174; (Ss. 15854–5). **Melaphyre,** amygdaloidal.

12 174–186; (S. 15856). **Amygdaloid.**
(11)

15 186–201; (Ss. 15857–8). **Melaphyre,** amygdaloidal; at 201 feet
(14) there is a decomposed green seam, which may be a vein or a
decomposed margin between two flows.

25 201–226; (Ss. 15859–62). **Melaphyre,** amygdaloidal. All the
(24) above series of amygdaloidal melaphyres are small flows of
the ophite type.

32 226–258; (Ss. 15863–7). **Melaphyre,** feldspathic.
(30)

17 258–275; (S. 15868). **Melaphyre.**
(16)

22 275–297; (Ss. 15869–71). **Melaphyre,** amygdaloidal.
(21)

23 297–320; (Ss. 15872–3). **Melaphyre,** ophite; amygdaloidal.
(22)

28 320–348; (Ss. 15874–7). **Melaphyre,** ophite; vesicular and amyg-
(27) daloidal, with laumonite, for the first 13 feet.

43 348–391; (Ss. 15878–82). **Melaphyre,** ophite.
(41)

19 391–410; (Ss. 15882–4). **Melaphyre,** amygdaloidal.
(18)

28 410–438; (Ss. 15885–7). **Melaphyre,** ophite.
(27)

10 438–447; (Ss. 15888–96). **Breccia** or **Scoriaceous Conglomerate;**
a mixture of fine grained sandstone and of a porphyrite like
5,849 the Huginnin porphyrite.

From this point we shall take off 0.06 to reduce from **vertical** *width to* **thickness,** *implying a dip of about 20°.*

20 455–475; (Ss. 15897–8). **Porphyrite;** like the Huginnin por-
(19) phyrite. No. XIV, 367–436 feet.
5,868

12 475–487; (Ss. 15899–906). **Conglomerate,** red, with numerous
(11) cavities, and much basic debris, but also with a great deal of
quartz porphyry which is sometimes spherulitic; cement
largely calcareous. This conglomerate which occurs in No.
XII from 471 feet to 493 feet, and in No. XV from 429 feet to
444 feet, being the first bed that can be identified with absolute
certainty in all the holes, is said by Stockly to contain *copper*

in No. XII (p. 95). This is natural, as drill hole No. XII seems, as we have said, to lie nearer the fault. This conglomerate would seem to be thickening toward the northeast, and while occurring at practically the same level in both No. XII and No. XVI, is 40 to 50 feet higher in No. XV, as already remarked, thus indicating the fault already studied (p. 90). This is really the first well-marked conglomerate with porphyry pebbles that we have met below the Allouez conglomerate, No. VI, 363-386 feet. It is about (5879-2332) 3547 feet below the latter, and in the remainder of the record we find four considerable conglomerates and at the bottom a porphyry. Now we see in Marvine's table of conglomerates facing p. 60,* that after a considerable gap devoid of conglomerates, we have a group, Nos. 8-4, opposite or east of the Isle Royale mine, and Nos. 6-4, opposite or east of the Kearsarge mine, about 6529 feet below the Allouez conglomerate. Now the ratio 3547:6529 is not far from the similar ratios already found (p. 83), 1736:2599 and (p. 68) 396:573. On Keweenaw Point, moreover, at the extreme bottom of our series, we find a porphyry—not only the quartz porphyry, 200 N. 600 W., Sec. 36, T. 56, R. 33, mentioned by Irving (pp. 104, 196; cf. Marvine p. 60), but also (in part more like the one at the bottom of No. XVI) one from the Suffolk mine at Praysville, 50 paces N., 1,825 paces W., Sec. 10, T. 57, R. 31 (Irving, p. 177); and 50 paces N., 1,450 paces W., Sec. 4, T. 56, R. 32; and 550 paces N., 1,400 paces W., Sec. 30, T. 56, R. 32; also at the Douglass Houghton ravine (U. S. G. S. Bull. No. 23, p. 43) on Sec. 36, T. 56, R. 33, near the east quarter post. Thus porphyries are evidently quite persistent in connection with a lower group of conglomerates, and we may also mention the porphyries found around Bare Hill and Mt. Houghton, which are much more like the Isle Royale occurrence in question. We have no marked change in the character of the lavas at this point as we have above the Greenstone, by which we can make an exact and certain identification, but we may with much certainty say that we have arrived at the top of the lower group of felsitic conglomerates, and as Marvine's No. 6 is the first one which he makes continuous, we will provisionally correlate this Isle Royale bed with it, for thus we best express its position at the top of a group of four closely following conglomerates. Of course the scoriaceous bed at 438 feet might be taken as Marvine's No. 6, in which case this conglomerate (475 feet) would be his No. 5, but the bed at 438 feet is not felsitic.

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* Geol. Sur. Mich., I, Pt. II.

124 487-611; (Ss. 15906-18). **Melaphyre,** ophite; amygdaloidal at the
(117) top: has much more magnetite than, for example, the "backbone"
greenstone. Cf. Pumpelly. Geol. Sur. Mich., I.
(5,996) Pt. II. p. 17.

7 611-618: (Ss. 15919-23). **Conglomerate;** with basic and acid
(6,003) pebbles: dips observed, 21°, 26°, 27°.

Hereafter 1-10 will be taken off to reduce from **vertical** *width to* **thickness,** *corresponding to dip of 26°.*

46 618-663.5: (Ss. 15924-8). **Porphyrite.**
(42)

33 663.5-697: (Ss. 15929-38). **Conglomerate,** scoriaceous: like 438-
(30) 445 feet in its character and in its pebbles. It is not at all unlikely that similar conglomerates, which are a brecciated mixture of sandstone and trap, represent real though perhaps slight erosion unconformities, the underlying bed having been eroded. Dips 28°, 29°.

89 697-786; (Ss. 15939-45). **Melaphyre,** ophite; the bottom five feet
(80) are a fine grained brecciated black trap, the dip of the lines of
(6,155) amygdules being 27°.

124 786-910; (Ss. 15946-85). **Sandstone,** passing into **Conglomerate**
(112) and **Porphyry Tufa.** Dips: at 796 feet, 52°?; at 803 feet, 50°; at 808 feet, in a sandstone streak, 63°; at 817 feet, 40°?; at 830 feet, with signs of unconformity and cross-bedding, 35°: at 850 feet, 37°. This bed is very largely of fragments such as the underlying rock might furnish, and largely in the concave forms of ash or glass fragments, which do not imply an erosion of the source, but at the top of the bed there is sediment proper, some of which may have been derived from other rocks than the underlying felsite. At the bottom of this conglomerate the passage into felsite is so gradual that I at first fixed the dividing line at 924 feet, and I think the conglomerate may be considered practically contemporaneous, that is immediately subsequent to the felsite, even though the former derives some of its material from the latter. Chalcedonic dots are characteristic of the whole formation (Rosenbusch, Vol. I, ii, i) and a bluish fluorite, first noticed under the microscope, was visible also to the unaided eye. The tufa is sometimes dark, but often light, often greenish, with sandstone boulders, or brecciated with angular green spots.

90+ 910-1000+; (Ss. 15986-98). **Felsite,** very fine grained; a typical
(80) felsite; porphyritic crystals, extremely small and rare; quartz not certainly visible. This, with the Minong felsite porphyrite may seem to meet Irving's anticipation (*loc. cit.*, p. 331) of red acid rocks on the north side of the island. We have already called attention to the felsites that occur at various points far down in the series on Keweenaw Point. But

by far the closest lithological resemblance of this bed is to the felsites of Bare Hill, Sec. 29, T. 58, R. 28, and to those that occur near the mouth of the Little Montreal River on Sec. 26, and Sec. 27, T. 58, R. 28, which are described elsewhere in this volume.

We add for completeness sake the record of hole No. XII from Mr. Stockly's notes, and of No. XV from samples gathered.

DRILL HOLE NO. XII.

13-79; **Trap,** gray.

79-107; **Amygdaloid;** sample from 107 feet?

107-168; **Trap,** amygdaloidal and chloritic; samples from 102, 160 and 165 feet.

168-174; **Amygdaloid.**

174-176; **Trap;** sample from 175 feet.

176-183; **Amygdaloid.**

183-228; **Trap,** slightly amygdaloidal near middle of belt; sample from 217 feet.

228-243; **Amygdaloid;** secondary minerals scanty; samples from 231 and 237 feet.

243-249; **Trap.**

249-264; **Amygdaloid;** secondary minerals very scanty; sample from 251 feet.

264-270; **Trap.**

270-276; **Amygdaloid,** with a little *copper.*

276-290; **Trap,** fine grained, black.

290-292; **Amygdaloid,** chocolate colored.

292-341; **Trap,** slightly amygdaloidal.

341-344; **Amygdaloid,** blended with underlying trap.

344-383; **Trap,** amygdaloidal near top.

383-398; **Amygdaloid.**

398-440; **Trap.**

440-457; **Amygdaloid.**

457-464; **Trap.**

464-471; **Amygdaloid,** poorly defined.

471-493; **Conglomerate,** with *copper.*

493-510; **Amygdaloid.**

510-602; **Trap.**

602-610; **Conglomerate,** with a fine sandstone near foot. Specimen from this bed probably?

610-616; **Amygdaloid,** well mineralized.

616-656; **Trap,** amygdaloidal near hanging and crumbly near foot wall.

656-664; **Sandstone,** mixed with amygdaloid near foot. Specimen from this bed probably.

664-683: **Trap,** slightly amygdaloidal.
683-796: **Trap,** fine grained, black.
796-807: **Amygdaloid.**
807-819; **Conglomerate,** made from broken amygdaloid.
819-843: **Amygdaloid;** specimen from 843 feet.
(53) 843-1054; specimen from the bottom showed that the drill was
6,400 still in the felsite. This adds some fifty feet to the section given.

DRILL HOLE NO. XV.

(Thin sections have not been made.)

0-24; **Amygdaloid.**
24-44; **Trap;** amygdaloidal for the first 11 feet.
44-64; **Trap,** with 6 feet of amygdaloid at top.
61-79; **Amygdaloid,** with green streak at top like No. XVI, 31 feet, 89 feet and 154 feet.
79-115; **Melaphyre,** ophite: amygdaloidal for first 15 feet and occasionally (pseudamygdaloidal) down to 98 feet, then lustre mottled and growing redder and finer grained.
115-124; **Amygdaloid;** green seam for the top 2 feet, then a marked laumonitic amygdaloid.
124-130; **Amygdaloid.**
130-135.5; **Amygdaloid.**
135.5-147; **Amygdaloid;** at 144 feet a *copper* and prehnite vein.
147-159: **Amygdaloid;** green seam at upper contact; lower contact brecciated.
159-164; **Amygdaloid;** green seam at top.
164-192; **Melaphyre,** ophite.
192-216; **Amygdaloid;** green seam at top with red veins at bottom.
206?-222?; **Amygdaloid.**
222-256; **Amygdaloid.**
256-265; **Amygdaloid.**
265-285; **Amygdaloid.**
285-294; **Amygdaloid.**
294-297: **Amygdaloid?**
Zones of finer grain at—
297 feet.
298 feet.
300 feet.
302 feet.
313 feet; green and amygdaloidal.
318.5; **Amygdaloid;** fine grained, with prehnite and laumonite.
323; finer grained streak.

323–385; **Melaphyre,** ophite; green and crumbling at 324 feet, and at 332 feet much broken; thereafter more compact; at 383 feet and 384 feet, as well as 385 feet, fine grained streaks. It seems as if there were a slide hereabouts, as above this point the series cannot be matched with No. XVI, while below it the matches are very good.

385–395; **Trap.**

395–403; **Sediment,** like that at No. XVI, 438–447 feet.

403–429; Cf. No. XVI, 455–575 feet.

429–444; Cf. No. XVI, 475–487 feet; **Conglomerate,** very red. Apparent dip 20°.

444–548; Cf. No. XVI, 487–611 feet; **Melaphyre,** ophite.

548–570; Cf. No. XVI, 611–618 feet; **Conglomerate,** not as red as above; much broken up; trap boulders (?) and breccia; dip 40°?

570–610; Cf. No. XVI, 618–663.5 feet; **Trap,** fine grained; nowhere very coarse.

610–626; Cf. No. XVI, 663.5–697 feet; **Sandstone,** passing downwards into a black breccia; dip 27°.

626–736? (Core box No. 23 was marked inside "715–736," outside "No. 25, 736- bottom"). **Melaphyre,** ophite, as in No. XVI.

We have been over the geological column in some detail, but before we leave it, it would be well to take one flying glance to see if there may not have been some repetition in the series on a grander scale than the mere overlapping of adjacent drill holes. If we can show that each hole has its peculiar character or contains some unique bed, i. e., one not elsewhere found in the series, we shall be sure that there is no mighty fault that has reduplicated the series on a large scale.

Beginning then once more at the south side of the island, drill hole No. XI is characterized by a large number of acid conglomerates, with small basic flows. No. X has the Island mine conglomerate, with all the peculiar relations and accompanying change in the character of the flows and conglomerates fully described on p. 61 *et seq.* It has also the first scoriaceous conglomerate, No. 44 of Marvine, from 415-426 feet. In drill hole No. IX we have a number of flows of a green acid type which give the hole a peculiar character, though similar things are found to some extent in the immediately adjacent holes. Their relations have already been fully discussed.

It has also the Ashbed series, p. 66. In No. VIII, beside the green porphyrite flows, there is a characteristic bed of chocolate sandstone, about 40 feet thick, with hardly any conglomerate, fully described on page 69.

In Nos. VII and VI we have the interesting and unique narrow band of felsite tufa, and, besides, in No. VI we have the Greenstone, the "backbone" and biggest ophite of all, with the bed at its base that we correlate as the Allouez conglomerate, p. 74. Nos. II, IV and V have no very marked character, though they are largely in heavy ophites, but we have stricken out of the column 276 feet there on the score of a fault. Nos. I and III have the very characteristic Minong group, porphyrite and trap. See p. 82. No. XIII is not so well defined, but No. XIV has the characteristic Huginnin porphyrite, p. 89, with its overlying and underlying large ophites.

The holes on the north shore of the island are quite characteristic, owing to the return of felsitic conglomerates once more and to the felsitic conglomerate and felsite at the base.

The table at the end of this chapter gives some of the principal beds, such as are used in the stratigraphic map, and also the probable correlations.

We have thus made sure that our column as given is a minimum, and that we have not overlooked any faults which would raise the south side, and make our section too long. But what can we say as to the other idea, that there may be faults which have let the southeast side down, and thus caused us unwittingly to leave gaps in our column, and not to make it as long as it should be?

Well, in many cases we have reasonably certain correlations, and in such cases no fault such as described could lead us astray. In the second place, such faults would cause us to find too steep dips from correlations, while in general the tendency is the other way—we find dips a trifle flatter than surface observations or than the observations in the drill cores would lead us to expect. In the third place, with a possible exception near drill hole No. IX, there are no southeastward facing scarps or other indications of faults of that character.

Thus there is little probability that our column is much too short. It may be worth while in this connection to notice that the distance between holes Nos. XI and XVI in a direction at right angles to the strike of the beds being about 23,518 feet, and the corresponding distance in our cross-section being 5,579 feet, the average dip between the two is 12° 40′, whose sine is 0.218. Thus if we had made the average dip 14° 30′ we should have made the thickness 5,880 feet, if 15°, 6,087 feet. If we had assumed a dip as high as 17° 30′ we should have obtained a thickness of 7,050 feet. Now if we had to depend on surface observations alone, we should probably have taken the dip as about 15°, and thus over-estimated the column some 500 feet.

§ 4. Isle Royale and Keweenaw Point cross-sections compared. This seems to be an appropriate place also to compare our column with those given by Irving. We have preferred to make our detailed correlations with the cross-sections of our own reports, i. e., Marvine's, which Irving also used as the base of his work. And first, as to his notes on the Eagle River section (p. 170 *et seq.* Copper-Bearing Rocks, Mon. V, U. S. Geol. Survey), Irving assigns a greater thickness to the Great Conglomerate at the top of the section than we think appears on the island. The bed is, however, probably thicker on Keweenaw Point, as it is there much coarser. Then his next group (No. 6 of his map, Pl. XVII), is Marvine's group (c), coming down to our drill hole No. X, 426 feet, to which he assigned 1,417 feet as against 817 feet in our section. We, like Irving, divided this group into two parts at the Island mine conglomerate, finding in the lower group on Isle Royale an approximation to the character of the lavas in Irving's lower division.

The next group Irving limits at the bottom, we at the top, of the Ashbed. He follows Marvine's figures, but on his map he unites the next group, the Ashbed group, with this as No. 5. The next group, still following Marvine's figures, he brings down to the top of the Greenstone, corresponding practically to our division at drill hole No. VII, 91 feet, which makes 2,045 feet from the top of drill hole No. XI. We also divided this group rather arbitrarily, in order to trace the big sandstone at No. VIII, 419 feet. The peculiar felsitic bed that we find at the bottom of this group, i. e., just over the Greenstone, has not been seen on Keweenaw Point.* The next group, No. 4 of Irving's map, Marvine and Irving consider as one series made up of several beds, the basal bed forming the Greenstone ridge, while we recognize in the corresponding group on the island but two beds. Moreover, as previously stated, I have been over the ground carefully around the Phœnix mine, and am convinced that the alterations of "dark diorite" and "light diorite" are merely streaks of magmatic differentiation into more augitic and less augitic parts, the variation in the grain of the whole showing that the ridge and the group are mainly one great flow. The coarsest mottling observed in the samples in drill hole No. VI was about 7 to 9 mm., about 0.4 of an inch. This is in a flow 233 feet thick. Around the Phœnix mine the mottlings steadily increase in size, as we go north over the bluff, from four to the inch to scarcely one to the inch (25mm), and at the latter point we are so far up over the bluff, that supposing the grain to begin at once to diminish here (which it does not, so far as we can see), and supposing therefore that this point is up to the middle of the flow, the remaining upper part of the flow would take up so much of the space intervening between this point and No. 90 as to leave scant room for any additional beds. As Irving remarks, in all this distance there are no intercalated amygdaloidal bands, and though the mind may shrink from lava flows 1,200 feet thick, no valid reason can be given why they should not occur, especially in face of distinct indications that they do occur. As to the evidence from coarseness of grain, see Chapter V.

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* I at first wrote as above—afterward my attention was called to the occurrences noted at the end of this chapter. See also p. 72.

This brings us down to that great datum plane, the Allouez conglomerate, which we correlate with No. VI, 363-386 feet, 2,310 to 2,332 feet below the top of drill hole No. XI. From here we have some 685 feet of the Phœnix mine group, feldspathic ophites with no marked bottom to the group, and then Irving has to leave the accurately measured sections of Marvine and estimate a region of few exposures, little developed, except for an exposure of conglomerate 500 feet south of the center of Sec. 33, T. 58, R. 31, which is called the Kingston conglomerate, but may in all likelihood be the Kearsarge. (Cf. Cliff mine section.) Marvine and Irving take it to be 3,000 feet below the Allouez conglomerate, but the recent developments at the Central mine render probable that they over-estimated the dip, and that it is really something less than 2,600 feet below the Allouez. This we have correlated with the Minong conglomerate, at No. I, 386 feet, 4,189 feet from the top of hole No. XI. The high ridges with coarsely lustre mottled ophites like the Greenstone, which occur in Sec. 4 and Sec. 9, T. 57, R. 31, may well correspond to the high ridges along the north side of the island with the big ophites exposed in drill holes No. XIII and XIV, and then we have Irving's No. 2 of his map, Pl. XVII, and the Praysville porphyry near the base of his group No. 1 to correspond to the bottom of our column. Irving has assumed for the dip from the Allouez conglomerate, or "slide," to the "Kingston" conglomerate, 30°. But if this latter is the Kearsarge and not a lower bed, the dip must be somewhat flatter. Then for the distance from this conglomerate to the Praysville porphyry he finds that the same dip would give 6,600 feet, to which to allow for a supposed increase in dip he adds 1,400 feet, making the total 8,000 feet, which would mean an average dip of 37° 20′. It is obvious that there is a chance for over-estimate here! Thus Irving (*loc. cit.* p. 177) gets a total thickness on Keweenaw Point of (15,190 + 2,200) 17,390 feet to our (6,555 feet + 2,600) 9,155 feet on Isle Royale, while within that part of the geological column where we can make close correlations, our Isle Royale section is about 2-3 of the thickness of the corresponding section on Keweenaw Point, which would in the same proportion be about 14,000 feet. It is probable that the greatest divergences are at the top and bottom of the section, and that our column may not represent a thousand feet or so at the top and that Irving's column may be exaggerated a thousand feet or so at the bottom. Moreover, Irving's section makes no allowance for possible faults except for a few minor ones that Marvine estimated.

On the whole the coincidence is fairly satisfactory, and warrants us in saying that we have represented on Isle Royale practically the whole of the Copper Range as it exists from the Central mine to Portage Lake.

At Portage Lake Irving estimates 11,000 feet of upper sandstone down to the first known diabase (the true thickness of which part of the section is very uncertain, depending as it does upon very uncertain dips), plus 11,680 feet of the lower Keweenawan, which latter is in tolerable harmony with our section.

§ 5. Isle Royale and Minnesota cross-sections compared.

When we come to compare our rocks with their nearest neighbors and allies of the Minnesota coast, there is much more uncertainty. In the first place I am not personally acquainted with these rocks, having made only a few trips around Duluth, and having sailed in a steamer up and down the coast. Fortunately, on this latter occasion the weather was beautiful, so that the steamer could go near shore and stopped frequently for mail and fish.

I do not pretend to be able really to geologize under such circumstances, but I would suggest tentatively, (1) that the faults noticed by Irving, transverse ones as well as those mentioned by Lawson as possible (Bull. Min. Geol. Survey, No. VIII, Laccolitic Sills, p. 33), might seriously affect Irving's estimates of thickness. Faults of the kind we have found on Isle Royale, running nearly north, must play havoc with the stratigraphy, if there is no way of estimating their effect, along a coast trending in the direction of the Minnesota coast. Moreover, if they are of the same character as the fault between drill holes Nos. XVI and XV, throwing the east side up (and such is the character of the faults referred to by Irving on pages 311, 312 and 329), the effect is to increase the apparent thickness of the column, as we approach the upper beds from the west, and to decrease the apparent thickness of the column, as we pass from the upper beds toward the east. Thus the apparent thinning of the column in going east, which Irving notices and finds hard to account for (pp. 294-295 *et passim*), may be in part perhaps explained. Irving has not failed to notice these faults; indeed some of them are obvious from the steamer, but it is a question whether he has given them their full stratigraphic value. It has been for some time a current rule with geologists not to allow any more faulting than can be proven. Now, unfortunately, a fault is of a very retiring disposition, and therefore it is difficult to get proof of it. We are therefore *morally certain to make an error* in following this rule, and it is a question whether we ought not, if we find a certain class of faults in any region as often as there is a chance to obtain the evidence of them, to compute and always keep in mind how much effect other similar but unproven faults may produce.

(2) It seems highly probable that, just as has been shown by Mr. Hubbard, in subsequent pages, for Keeweenaw Point, so here there is much more intrusive felsite than Irving realized. Such is certainly the general appearance. I submit for example that the figure and description given by Irving, on p. 323 (*loc. cit.*), would be even more natural, if we supposed the felsite intrusive.

I shall not attempt then any close numerical correlation with Irving's enormously thick Minnesota column. Yet I think Lawson has gone much too far in reaction, for I have had his ideas in mind and have examined my column with them constantly in view. We have shown a thickness of at least 7,000 feet of the Keweenawan series on Isle Royale with neither top nor bottom reached, so that the few hundred feet allowed by Lawson is likely to be far within the truth. (Anorthosytes, Bull. Minn. Geol. Sur., No. VIII, 1893, p. 21.)

I sincerely hope that the cross-section here given may be a key to some Minnesota geologist to help unlock the more complex stratigraphy of the north shore of Lake Superior.

'Beginning then, at the top of Irving's series, ·the Temperance River group, VIII of map, Plate XXVI, ad VI of text, p. 268 (Copper Bearing Rocks, Mon. V, U. S. Geol. Survey), we find these beds described as like the layers of the Upper and Middle Keweenawan, with thin diabase flows amygdaloidal at top, more massive below; often ophites (p. 324) with ashbed diabase and diabase porphyry (i. e., our melaphyre porphyrites, and scoriaceous amygdaloidal beds) only toward the base (p. 326). This evidently matches the beds of our section down to drill hole No. VII, 81 feet. There are also in the above group numerous interbedded sandstones and conglomerates. The rock of the point at Grand Marais, with the brown color and large porphyritic plagioclases, reminds one of some of the beds immediately above No. VII, 81 feet.

The next group below, the Beaver Bay group (p. 267), is largely of coarse grained rocks, olivine gabbro with lustre mottlings (pp. 43, 322). This appears to answer very well to the Greenstone range. Of the red felsitic rock which seems to occur so abundantly in this connection along the Minnesota coast we have only the 10-foot bed from No. VII, 81 to 91 feet, as representative, corresponding to a widespread tufa. While Irving mentions the great predominance of coarse grained rocks, he also mentions fine grained rocks and traps of which we have no representatives. They may not extend to Isle Royale, or the Beaver Bay group, to which he assigns a thickness of 4,000-6,000 feet, may include lower beds than the Allouez,—our No. VI, 363 feet, or finally these finer grained beds may have been faulted into the shore line. We are tempted to think this last suggestion true, in order to correlate the Agate Bay group with the small amygdaloidal flows underlying the Greenstone, as shown in hole No. II. Then the diabase porphyrite of the Cascade river, Sec. 26, T. 61, R. 2 W., might be the Minong trap, and the felsite of the falls in Sec. 10 (p. 295) might be the felsite that we find at the bottom of our column. These Minnesota correlations must be considered merely as suggestions, but they seem to indicate that the Keweenawan series in Minnesota is even thicker than on Isle Royale, and I cannot agree with the correlations of Isle Royale proffered by N. H. Winchell (American Geologist, XVI, 1895, pp. 160, 270, 333), which are founded on a misunderstanding of the stratigraphy. See below, § 12, in Chapter V on grain.

From descriptions of Michipicoten Island, Lake Superior, (Herrick, Tight and Jones; Bulletin of the Sci. Lab. of Denison University, 1887, Vol. II, part 2), it would appear that the sedimentary beds there are peculiar in containing a large number of pebbles of the Huronian and Laurentian, and that the melaphyres are not highly augitic, but seem to be equivalent to the upper beds of Isle Royale, the melaphyre porphyrite or Ashbed type, rather than to the ophites. Felsites occur on Michipicoten and not high in the series on Isle Royale.

The subjoined table indicates some of the correlations suggested.

Name.		Drill hole.‡	Depth in drill hole, feet.	Total thickness from 0 feet.	No. in Eagle River section.	Thickness in Eagle River section.	Copper Falls section.	Tamarack section	Conglomerate numbers.	Distances.	Minnesota correlations.
Upper sandstone and conglomerate				2600	2500						
First known trap	Marvine's (c).	XI	0	0	No. 1						Temperance River group?
Small ophites, numerous sandstones											
Island mine conglomerate		X	170 193	567 589	35	1146	1035 1012	2146	18?		
Transition flows, porphyrite and ophite											
Scoriaceous conglomerate	Marvine's (b).	X	415 426	806 817	44	1417	745	2021	17		
Green porphyrites											
Scoriaceous conglomerate—"Ashbed"		IX	279 291	1100 1112	63 65	1810 2035	368 160	1639	17	853 885	
Porphyrites	Marvine's (c).						+0↓				
Red sandstone		VIII	377 419	1526 1567	80?	2432 2496	495 500	1081 1053	16	1435 1445	
Porphyrites, etc.		(VII)	81	2035				160	*		
Felsite tuff		VI	91	2045							
Ophite, and the thickest ophite—the Greenstone		VI			90 108	2840 4120	Centr'l mine.				Beaver Bay group?
Conglomerates—the Allouez or "Slide"		VI	363 386	2310 2332			0↑	↑0↓	15	2345 2378	Agate River group?
Amygdaloids mainly and thin ophites		II IV (V)	136 175 133	2570? 3197			660 1474	 1309	14 13 12		
Minong breccia		I	386	4030	"Kingston" or Kearsarge?					4853	
Minong porphyrite		(III)	426	4068			2599	2239	11	4873	
Minong trap			456 536	4097 4174							
Various beds ending with a thick ophite		XIII A									
Huginnin porphyrite		XIV	367 436	5194 5260							
Ophites											
Felsitic conglomerate		XVI	475 487	5868 5879					6	7643	
Various igneous flows and conglomerates											
Felsitic conglomerate and felsite tuff			786 910	6155 6267							
Felsite		XII		6400	Praysville.						

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* 67.7 above Allouez at Peninsula mine. ‡ The depths in drill hole refer to the drill holes whose numbers are not enclosed in parentheses.

CHAPTER IV.

THE GRAIN OF ROCKS.

§ 1. Conditions that affect cooling.

There is one subject, for the study of which the possession of a suite of specimens whose position in the flow was at least approximately known, has given me especial advantages. That is the variation in the grain of the rocks. And while the methods of study require the aid of the microscope in so many cases, yet the general variation in grain is plain even to the unaided eye, and the practical interest and bearing of the subject (for example, in identifying flows or in foreseeing how far we may have to go to pierce through a belt) so immediate, that it has seemed to me well to devote a separate chapter to the subject, and not only give a few general observations which can be readily understood by anyone, but to develop the more mathematical part of the subject.

It is a well known fact of general observation that the more rapidly a solution is caused to deposit its crystals or to solidify, the finer the grain is, until if it is cooled very suddenly the atoms have no time to arrange themselves with any regularity with regard to each other, and a glass may result. The principle holds good either of solidification, or of precipitation, or of crystallization from solution. In fact there is no sharp distinction between precipitation and crystallization from solution. We call it precipitation when the separation of a solid out of a solution is very rapid, and in such case the grain of the resulting product is, in accordance with our general law, often very fine but not always impalpable. Sometimes, indeed, the highest power of the microscope cannot detect the grain.

This precipitation may be produced in various ways. It may be produced by the addition of some precipitating agent which forms a new chemical molecule in such quantities as to be no longer soluble. This agent may be either a liquid or a gas. Thus oxygen acts upon the ferrous salts, and slowly precipitates the ferric hydrate. By an analogous process, Lévy considers the oxides of iron to be often formed in the volcanic rocks. Carbon dioxide or carbonic acid gas (CO_2) thus precipitates the calcite from limewater. Precipitation may also be produced by the loss of a dissolving agent. The common method of evaporating mineral water until only the solids are left is an obvious illustration, but the application of heat is not always necessary. The spontaneous escape of carbon dioxide often produces precipitation, and thus the calcareous sinter around the mouths of springs is formed. Again, relief of pressure may produce precipitation, both by facilitating the escape of gas, and more directly.

Finally, the loss of heat is a frequent cause of precipitation and of solidification, one of the most obvious of all. That here, too, the size of the grain depends on the rapidity of the process, is known to every one, for candy quickly cooled is clear as glass, while the more slowly it cools the more coarsely it sugars. Good illustrations of this may also be seen in the fusible slags, such as come from copper smelting. When the slag is let run away in sheets, the quickly-cooled outside is a glass, while the center of the stream is distinctly granular. Pour the slag into a pot and let it stand so that the interior cools very slowly indeed, and we shall find there large crystals, even up to a centimeter across (Bull. Geol. Soc. Am., VI, 1894, p. 469). But whatever the process, the rule is the same: the slower the action, the coarser the grain.

In considering the solidification of rocks, we are by no means entitled to say that any of the above causes has been entirely inefficient. That the loss of heat is the chief agent in the stiffening of modern lavas we will all admit, but when we find a zone of finer grain around an amygdule, such as is shown in S. 15811 (Pl. VI) from drill hole No. XIV, 370 feet, it looks as if the escape of gas into the bubble had accelerated solidification. It is also generally understood that the more siliceous a glass or a slag or a molten rock is, the quicker it is to cool. The only thing left for us, then, is to find out what effects a given cause (say cooling) would theoretically tend to produce, and then see how far we can distinguish these effects in practice.

§ 2. Loss of heat.

We will first take up heat, and its loss. The loss of heat and the laws of conductivity have been fully worked out, on the supposition that the conductivity is constant and the rate of flow proportional to the difference of the temperature, first by Fourier.*

Let us consider how the rate of loss of heat will vary from center to margin of a cooling mass of lava, and how the grain will be thereby affected. But first we must put in the warning that, since diffusing gas follows practically the same laws of loss as heat, the effects for these two agents of solidification cannot be separated. Nor is any account taken of the pauses and irregularities in cooling which may be introduced by the formation of new chemical combinations, attended with the liberation of latent heat. We can see, however, that such irregularities will be more likely to affect the earlier formed minerals, than that which is latest to crystallize, since it is not likely that such a chemical rearrangement of atomic affinities could take place, without altering also the character of the mineral which was forming.

In order to fix our ideas, we will suppose that we are considering a sheet of lava of indefinite extent, so that in our discussion we need only to consider one direction, that at right angles to the surfaces of the sheet, in which direction the cooling will take place. Our results will be approximately true for more irregular masses, and practically true for dikes and flows. We have then three quantities which are connected, the time since the lava arrived in its present form (t), the distances from the margins (x), within which the temperature will steadily fall, and beyond which it will at first rise; and finally the temperature at a given time and point (u). Having thus three variables, the time, the position, and the temperature, their mutual connection, if exhibited graphically, must be in the shape of a surface. Thus the main diagram of Plate IV shows such a surface for a sheet whose sides are kept at a fixed temperature. The sheet is supposed to have had the same temperature throughout at the start. We are supposed to be looking in the direction of the thickness, so that the axis along which the distance from the margin would be laid off is pointing directly toward us. Then we have a series of twelve contour lines, representing, if for example the dike is 240 feet thick, intervals of ten feet up to the center. Each contour line shows the relation of the temperature, and its gradual loss with the lapse of time, for the corresponding distance from the margin of the dike.

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*In the mathematical part I shall follow Riemann, "Partielle Differentiell-Gleichungen," Braunschweig, Vieweg, 1882.

We see at a glance that at the margin the temperature drops very suddenly at first, then steadily but very slowly thereafter, while at the center the temperature falls very slowly at first, and steadily but more rapidly thereafter. This diagram is mathematically accurate only for a particular case, but the principles it illustrates are often of wider application. We can see that in any cooling body, under any conceivably probable law of cooling the center would cool very slowly, almost not at all at first, then faster, and finally when it got down nearly to the temperature of the walls, more slowly again. This gives the form of the outside of the family of curves. It is obvious, too, that as we approach the margin the temperature would drop more rapidly than at the center. Concerning the exact extent to which the above principles can be applied, reference must be made to the mathematical appendix.

In such a diagram the relation between the vertical scale of temperature (the fixed temperature of the sides being taken as 0) and the horizontal scale of time depends upon the conductivity, and is a matter to be determined by experiment. The *same diagram* may be made to suit *any thickness of the sheet* and any *temperature*, by making suitable alterations in the horizontal time scale. Moreover, by laying off the temperature scale in various ways we can allow for any variation in conductivity that is dependent only on the temperature. A variation in conductivity dependent on other things, such as, for example, chemical composition varying in different parts of the flow, cannot be thus allowed for.

Now, an interesting thing will be noticed of our contour curves, that, except in the first two-tenths counting from OY, they cut any line parallel to OX at the same angle. That is to say, after the temperature at the center has fallen about one-fourth of the interval between the initial temperature and the marginal temperature, *the rate of cooling at a given temperature is the same for all parts of the sheet.* For example, in the little triangle OMN the time required to drop from N to O, or as taken in this particular case, from 420° to 400°, *i. e.*, 20° in temperature, is represented by OM, and the ratio of OM : ON is obviously the same if the angle MNO remains the same.

Now can we express the effect of this law on the coarseness of grain?

It is plain that crystallization cannot take place above a temperature which would melt the mineral. It will certainly stop above a temperature at which the whole mass consolidates as a glass. It does not necessarily follow that it will take place all the time that the lava is within these limits of temperature, but the latter certainly constitute extreme limits. Now the limit thus furnished is often quite narrow, compared with the whole range of temperature to be considered (Fouqué-Lévy; Synthese des Roches, pp. 50 and 74). For example, Barus found for a certain diabase that it consolidated at about 1093° C., and the fusion point of augite is below 1200° C. Thus we may imagine very plausibly that, other things being equal, the grain of the augite in a basic rock will depend upon the time required to cool from 1200° to 1100° C., and if this is the same at different points the grain of the augite will be the same also.

§ 3. Zones of varying grain.

There are two other things concerning the rate of cooling that we can notice.

First, it becomes constant for a given temperature first at the center of the sheet, and the condition of uniformity in rate of cooling for a given temperature gradually spreads toward the margin or surface of the sheet, reaching there for lower and lower temperatures.

Second, the mathematical treatment shows that whenever a certain portion of the sheet has reached this condition of uniformity in cooling, the temperature thence to the center may be expressed by a sine curve. That is, if a section be cut across the surface represented in Plate IV, parallel to OY, and perpendicular to OX, the section of the surface will give a sine curve for such part of the surface near the center as has become subject to the law of constant rate of cooling.

Our figure is drawn on the supposition that the margin of the sheet is kept constantly cool. As can be shown, we may withdraw that supposition and still express our results as follows:

If the initial temperature and conditions of cooling are such that a considerable time elapses before any part of the *sheet reaches the point of solidification, the rate of cooling will be the same at all points, and so far as the grain is dependent on it there will be no change of grain, but the grain will be uniform from margin to center.* By initial temperature it must not be forgotten that we mean, not any hypothetical temperature far down in the earth which the magma may have once possessed, but the temperature that it had when it came to rest at or within a given horizon with the margins that it retained. Such conditions will occur when the initial temperature of a magma is considerably more than twice the temperature of solidification, these temperatures being measured from the temperature of the surrounding medium as 0°. This surrounding medium may itself be hot and not far below the temperature of solidification, in which case we shall be almost sure to have the above conditions.

It is an easy consequence that, *the hotter the dike or sheet initially, the less will be the width of the marginal zones of gradually finer grain;* also, *the hotter the country rock, the less pronounced will be the marginal zone of finer grain.* This conclusion may be emphasized by the fact that in hot country rock we shall lose the convective cooling effect of water.

Thus, obviously, deep seated, *i. e.*, abyssal or plutonic rocks, will be expected to show less marginal variation in grain than more superficial formations of the same chemical character. Conversely, the broader the marginal zone of varying grain in a rock, the nearer its solidification point we may suppose the rock to have been when it came to rest. The presence of fusible porphyritic crystals, obviously formed while the sheet was still in motion, also points to a temperature not high, at the end of the period of motion, and generally we should rather expect surface flows to continue in motion until they began to stiffen. Such considerations will aid us in checking our results. It appears *a priori* probable, therefore, that an especially frequent case for effusives may be expected to be that of solidification beginning immediately at the cessation of motion, and the grain steadily increasing up to the very middle.

§ 4. Relations of sheets with and without fixed marginal temperature.

The case where the surfaces of a sheet are kept at a fixed temperature, as would be practically true, for example, in a submarine flow, is one especially easy to solve, and is the one whose solution is graphically given in Plate IV. Mathematical investigation has also shown that the more general case, where we consider the adjacent rock symmetrically heated by the sheet, can be solved by aid of the solution for this especial case. For, suppose that the sheet or dike (whose width is 2 w) is, at its injection, of a uniform temperature (u°) and that its effect on the adjacent rocks, whose initial temperature is taken as 0° of the thermometric scale, is confined to a certain symmetrical zone (c), of which the dike occupies the center. Then it may be shown that we may find the temperatures of the zone (c), which includes both the dike (w) and the contact zone on each side, by comparison with the temperatures which a dike of equal thickness (c) would have, starting at the same time from the same initial temperature (u°), very simply as follows:

The temperature at any point of the affected zone (c) for the case that we consider the contact heated, is the average of the temperatures which two points, P_1 and P_2 (Fig. 13), would have that were

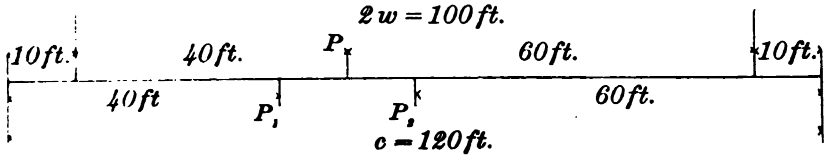

Fig. 13

Illustrates the relation of a sheet one hundred feet thick, having a ten-foot contact zone on each side, to a sheet one hundred and twenty feet thick, whose walls are supposed to remain at a fixed temperature. From these data the temperature of the former sheet may be deduced.

at the same distances from the walls of the hypothetical cold walled dike of breadth (c), as the point whose temperature is sought, is from the two walls of the smaller dike with breadth 2w; the sum of the temperatures being taken, if said point is within the small dike; the difference, if it is outside in the contact zone.

Let us illustrate this by a numerical example. If the original dike is 100 feet thick and affected the temperature of the adjacent strata for 10 feet on each side, then a point (P) 10 feet from the center of this dike is 40 feet from one margin and 60 feet from the other. Its temperature at any time is the average of those which under otherwise similar conditions of time and temperature, two points (P_1 and P_2) would have, one 40 feet the other 60 feet from the sides of a 120 foot cold walled dike. This we may find from Plate IV. After the time 2, the temperature at 60 feet from the margin will be 626°; the temperature at 40 feet from the margin will be 556°, the average, *i. e.*, the temperature of the point (P), 10 feet from the center of the 100 foot dike, will be 591 feet.

If the 100 foot dike had had its sides kept at the uniform temperature, the temperature of this same point would have been only 487° in (10,000÷14,400, *i. e.*, about) two-thirds of the time, after the cooling began, as we may see by using Plate IV again, and the fact referred to in the following section, that the times of cooling of a 100 foot cold walled dike and a 120 foot cold walled dike are as the squares of their linear dimensions.

We thus see how much the heating up of the walls retards the cooling of the dike. Hence lavas poured forth or intruded where there is a chance for aqueous convection, will show more marked effects of rapid cooling and solidification.

We may also remark that if one side of the sheet were bounded by an absolute non-conductor, there would be no cooling in that direction, and we could consider that surface as the center of the flow from which the cooling takes place. Such considerations give us a clue to the kind of effect which non-conducting walls produce.

Another example: Let the point whose temperature is sought be 5 feet outside the 100 foot dike. The distances to its walls are then 105 and 5 feet; the corresponding temperatures in the 120 foot dike (the temperature at 105 feet from the margin is the same as at 15 feet) are 246°, and subtracting 84° = 162°, whence the temperature sought is 81° (at same time and under similar circumstances).

In the same way we find the temperature at the margin of the 100 foot dike at the same time to be 160°.

This enables us to reduce all practical questions immediately to that of a sheet which has little or no effect in heating the adjacent rocks, and as that is the case which is of immediate practical application to the rocks we are studying, we shall confine farther attention to this particular case alone, merely remarking in passing that in the case of heated walls the temperature at the sides of the hot injected dike begins immediately to cool from a point half way between the initial temperature of the dike and that of the contact zone, and these sides cool very slowly at first, more slowly than does the center of the dike when it has cooled down to the same temperature. Thus a mineral forming at that temperature might have actually coarser grain at margin than at center. Such may have been the conditions of the formation of the feldspar in some granites.

§ 5. Conditions of initial cooling.

Another consequence of the mathematical solution of the cooling problem is that if we suppose the initial temperature of the sheet uniform and the cooling symmetrical, we find that if we increase all the linear units in the same ratio, and the time by the square of that ratio, there is no change made in the temperature. In other words, *the time of cooling varies as the square of the thickness of the dike or sheet*, so that a dike 200 feet thick will cool four times as slowly, other things being equal, as a dike 100 feet thick. In case the contact zone is negligible we can say more precisely, other things being equal, that any point in a flow will take four times as long to cool as a point half as far from the margin of a flow half the size. This may be pushed to a farther conclusion. If at the time of considering the two points just described, the centers of the dikes had not cooled perceptibly, it is obvious that it would have no effect on the temperature at the two points, if we replaced the farther half of the sheet with any thickness of material at the initial temperature. In other words, so long as the center of the dike has not cooled perceptibly, the dike might be indefinitely larger without affecting the cooling and solidification of the parts between the center and one margin, and if we should consider the smaller of the two sheets mentioned split, and sufficient matter at the initial temperature injected to make it as thick as the larger dike, this would not, up to the time that the center of the smaller dike began perceptibly to cool off, affect the grain. Hence the larger dike would have the same rate of cooling at the same distance from the margin as in the original even smaller dike. Then, *before the center begins to cool off, the time required for a given loss of temperature for any point will vary as the square of its distance from the margin.* This is practically the case where only one margin needs to be considered, and is therefore the same result as is derived by Riemann in somewhat different fashion (*loc. cit.*, pp. 8, 82, 131). Thus the ratio of cooling will steadily increase toward the center, from the time the margin attains a constant temperature to the time the center begins to cool off, and the curve indicating the time required at the very beginning for a given loss of temperature will be parabolic in form with its apex at the margin. (Pl. IV, fig. A.)

The above are some of the principles to be applied in considering the cooling of a sheet of lava. Their exact mathematical expression depends of course on exact mathematical formulæ (see appendix to this chapter), and we have given above only a popular resumé. How far they apply, must be tested by comparing them with curves expressing the coarseness of grain of various rocks, and seeing how far the curves are similar. This is the subject of the next chapter. We can, however, see that in the basic rocks they have some applicability, at least in the roughest sort of way. It is known that the great masses of plutonic rocks are coarser and more even grained in general than smaller and more superficial flows, and this is especially true when the former have perceptibly altered the neighboring rocks, producing a contact zone. We know, too, that not infrequently from a narrow glassy margin a dike will develop suddenly a certain coarseness of grain (*cf.* Lawson Am. Geol., VII, 1891, p. 153), and thereafter the grain will remain nearly uniform. These facts are in general harmony with those that the theory of cooling would indicate.

APPENDIX TO CHAPTER IV.

MATHEMATICAL TREATMENT OF COOLING PROBLEM.

Let u be the temperature of any point of the sheet, at t, a certain time after the beginning, and at a distance, x, from some fixed plane parallel to the margins, which are supposed to be parallel. The suffix, o, refers to the beginning of the time considered.

The general equation of cooling is:

$$(1) \qquad D_t u = -a^2 D_x^2 u$$

Of this a particular solution is:

$$e^{-a^2 \alpha^2 t} . \sin \text{ or } \cos . \alpha \ (x - l)$$

e is the logarithmic base = 2.718282.

By varying x and l (x and l are arbitrary constants which we can choose at will) we must build up a solution of eq. (1) which will satisfy the other conditions of our problem. Now, if we suppose that at the point from which we choose to measure our x, our origin, we are so far from the dike or sheet that at the origin the temperature remains unaffected by the temperature of the sheet during the whole time under discussion, and that on the other side of the sheet, at the distance c from the origin, the temperature is the same and equally unaffected, and if we take the temperature of the origin as the zero point of our thermometric scale, so that u is always o except within these limits, and assume also that the temperature of this sheet to start with (u_o) is a function of x, f (x), these conditions may be expressed as,—

(2) $u_o = f(x)$.

(3) $u = 0$ if x is less than o or more than c, and we may build up from the particular solution above, the following equation which will satisfy eq. (1)

$$(4) \qquad u = \frac{2}{c} \sum_{n=1}^{n=\infty} \sin (n \pi x/c) . e^{-(n \pi a/c)^2 t} \int_0^c f(l) . \sin (n \pi l/c) . dl.$$

Suppose, as we are including the contact zone, that the breadth of the sheet is (w) and that the center of it is at the distance (m) from our origin or starting point. Then we will naturally assume that—

(5) $u_0 = 0$ for x less than $m - w$ or greater than $m + w$.

Moreover, for the sake of abbreviation we will write—

$$(6) \qquad q = e^{-(\pi a/c)^2 t}$$

where q is a function of the time and the only one into which the time will enter.

Since $u_0 = 0$ and also $= f(x)$ outside the limits of $m - w$ and $m + w$, the f (l) of eq. (4) will also be 0 outside these limits, and hence the integration indicated in eq. (4) need be extended only to these limits, i. e.,

$$(7) \qquad u = \frac{2}{c} \sum_{n=1}^{n=\infty} \sin(n \pi x/c).\, q^{n^2} \int_{m-w}^{m+w} f(l).\, \sin(n \pi l/c).\, dl.$$

Now if the temperature of the sheet is uniform at the start, u_0, and therefore f (l), will be a constant between the limits indicated, and the integration can be easily performed. We shall have to change dl to d ($n \pi l/c$), which we may do if we divide the rest of the equation by $n \pi/c$. Moreover, f (l) being constant and equal to u_0, may be removed outside the integration, so that our expression to be integrated comes to have the simple form sin y . dy, where y is $n \pi l/c$. The integral is known to be (- cos y), that is - cos ($n \pi l/c$), and replacing l by the limits of integration, we have the expression

$- \cos(n \pi (m + w)/c) - (- \cos(n \pi (m - w)/c)$,

wherewith to replace the integral in eq. (7)

This expression may be much simplified by applying to it the formula (Chauvenet's Trig. eq. 104).

(8) $\cos(x + y) - \cos(x - y) = -2 \sin x.\, \sin y.$

It is thus transformed into

$2 \sin(n \pi m/c).\, \sin(n \pi w/c)$

Whence, making all the indicated substitutions in eq. (7)

$$(9) \qquad u = \frac{4}{\pi} u_0 \sum_{n=1}^{n=\infty} \sin(n \pi m/c).\, \sin(n \pi w/c).\, \sin(n \pi x/c).\, \frac{q^{n^2}}{n}$$

an equation particularly easy to remember from its symmetrical relations with regard to x, m and w. It is obvious, as u_0 is simply a factor of the whole expression for u, that *increasing the initial temperature increases the temperature at any time and place in the same ratio.*

If we increase m, n, x, and c in the same ratio, the equation will not have the value of its last half altered, since only the ratios are involved, except in the term q, which, on turning back to eq. (6), we see involves c. We can restore q to its value by increasing t in the square of the ratio in which c is increased. Hence it follows that: When the linear scale of the phenomena is doubled, that is, the dike or sheet of twice the size, and the external zone whose temperature is affected also doubled, it will take four times as long for a point in corresponding position to reach the corresponding temperature.

This is the foundation of the principle referred to on page 114.

Now let us take up the special case where the walls of the sheet are kept at a constant temperature, so that the breadth of the contact zone is 0. In such case eq. (9) becomes

$$(10) \qquad u = \frac{4}{\pi} u_0 \sum_{n=1}^{n=\infty} \sin^2 (n\,\pi/2).\ \sin\ (n\,\pi\,x/c).\ \frac{q^{n^2}}{n} \text{ when } w = c/2 = m$$

Now $\sin^2 (n\,\pi/2)$ will be alternately 1, 0, 1, 0, according as n is odd or even. Hence the series for eq. (10) expanded will be

$$(11) \qquad \frac{\pi}{4}\frac{u}{u_0} = q \sin (n\,\pi\,x/c) + \frac{q^9}{3} \sin (3\,\pi\,x/c) + \frac{q^{25}}{5} \sin (5\,\pi\,x/c) \cdots\cdots +$$

This is the equation whose numerical solution has been calculated out for twelve different ratios of x/c, and for values of q ranging from 0.99–0.10. It is obvious from a glance at eq. (6) that at the beginning, when t is 0, q will be equal to $e^0 = 1$. In the same way, as t becomes larger, q becomes smaller and at length approaches 0. The whole range of q is then between 1 and 0, so that by substituting the values of q given, we can get a sufficiently complete idea of the variation due to it. It is obvious, too, that as soon as q^4 becomes so small that it is negligible with relation to q, the series of eq. (9) and (10) will reduce to their first terms. Suppose for example that q is 0.10, then $q^4/2$ is 0.000,05. In eq. (9) the q term is multiplied by three sines, but as the sine of twice an angle cannot possibly exceed twice the sine, the whole second term must be less than 0.000,4 of the first. This gives some idea how rapidly the series converge when q becomes small, i. e., after a little time has elapsed. Through this period

(12) $\pi/4.\ u/u_0 = \sin(\pi\ m/c).\ \sin(\pi\ x/c).\ \sin(\pi\ w/c).\ q.$

At any given time, (i. e., q being considered constant) the temperatures will vary for various values of x in the form of a sine curve which touches 0° at $x = o$ and $x = c$, in accordance with our original condition (eq. 4). Such curves will be sections of the surface of Plate IV perpendicular to the axis OX, toward the right hand end of the surface. If, while q and the time vary, we assume a fixed and given ratio of $x : c$, a section of the surface becomes a logarithmic curve, which is what the curves of Plate IV tend to become toward the right, curves which represent sections of the surface parallel to OX, while the sine curves would be perpendicular to OX.

If, moreover, we seek $D_u t$, differentiating both sides of eq. (12) and remembering that t is involved in q,

(13) $\pi/4.\ u_0 = \sin(\pi\ m/c).\ \sin(\pi\ x/c).\ \sin(\pi\ w/c).q.\ D_u t.\ (-(\pi\ a/c)2)$

or substituting from eq. (12) so as to eliminate x, divide through both sides of eq. (13) by the corresponding sides of eq. (12), and we have

(14) $1/u = -(\pi\ a/c)2\ D_u t.$

In other words, the variation in the time required for a given small change in temperature is inversely proportional to the temperature, so that the lower the temperature the greater the time required for a small change, while *the rate of change of temperature is independent of the position of the point,* in this sense that at a given temperature heat is lost at the same rate, wherever the point considered may be. This, it must be remembered, is only true after such a time that the series of equations (9) and (11) may be represented by their first terms, after which time obviously, therefore, the grain will be independent of the position of a point, so far as the grain is dependent on the temperature or its change.

Removing this condition now, we will return and see what can be done toward simplifying eq. (9), so that its solutions may be easily derived from those of eq. (11). This we can do in case the contact zone is symmetrical, so that we can write—

(15) $m = c/2.$

The only part of (9) that needs remodelling are the sine terms. Otherwise the expressions (9) and (11) are similar. Therefore we will take sin (n π m/c) sin (n π w/c) sin (n π x/c) and remodel it by substituting (15) and writing $z + m = z + c/2$ for x, in which case z will be the distance of the point from the center of the sheet. Making these substitutions we have: sin (n $\pi/2$) sin (n w/c) sin (n π (z + c/2) /c)

(16) $z = x - m = x - c/2$.

Now by Chauvenet's Trigonometry (36) from sin (n $\pi/2$) sin [n π (z/c + 1/2)] we get sin (n π z/c). 1/2 sin (n π) (and this is 0 for all whole values of n which alone need to be considered) + (cos. (n π z/c) sin² n π/2.

Now out of this last expression we can take cos. (n π z/c) and combine it with sin (n π w/c), by Chauvenet (101), and we have for the remodelled eq. (9).

(17)

$$u = \frac{4}{\pi}.u_0 \sum_{n=1}^{n=\infty} \sin^2 (n \tfrac{\pi}{2}) (1/2 (\sin \left[(n \pi/c)(w+z)\right] + \sin \left[(n \pi/c)(w-z)\right]) \frac{q^{n^2}}{n}$$

Or, if we write, u_{w-z} for the value which u would have from Eq. (10 , if x were equal to (w — z), and u_{w+z} the corresponding value for x equal to (w + z), we may rewrite (17)

(18) $u = 1/2 \left(u_{w+z} + u_{w-z}\right)$

The meaning of which has been stated above (Chap. IV, § 4, p. 112). It is to be remarked that if w — z is itself negative, we must consider u_{w-z} as negative, i. e.

$$u_{w-z} = -u_{z-w}$$

Practically then the numerical calculation for the sheet with margins of fixed temperatures is sufficient. In preparation for the computation and construction of Plate IV, I have compiled the table appended to this chapter, Table IV (three places accurate), showing the sums of the series of eq. (11), i. e., the temperatures, for an initial temperature of $\pi/4$, i. e., 0.7854, for points every 24th of the way across the sheet, and for values of q every tenth up to 0.9 and every hundredth thereafter.

In the same table is given log. q; for, from eq. (6) it follows that

(19) $\log. q = -\pi^2 a^2 c^{-2} t$

and is thus directly proportional to t. Thus by choosing the unit of our scale properly, i. e., equal to $-\pi^2 a^2 c^{-2}$ and laying off our abscissæ proportional to log. q, they will represent the time.

Thus in the large figure of Plate IV we have the ordinates representing the temperature, the abscissæ representing the time, while the curves correspond to the various distances from the center of the dike, the outermost representing the temperature at the center of the dike at various times, the uniform temperature of the margin being taken as 0° of our thermometric scale and 0.7854 as the initial temperature.

Taken together these curves may represent the contours of the surface which connects together the three variables, time, temperature and position in the dike. Sections of this surface for a given time, i. e., perpendicular to OX, the axis for the abscissæ of time, will, near the beginning of the time, give us curves of the form familiar to us in the discussion of the cooling of the earth* (e. g., C. P. Q. in Thomson and Tait's Natural Philosophy, Vol. I, Part II, p. 477).

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* In fact our problem is closely akin to that of the cooling of the earth, and the solution of our eq. (10) p. 118, may be made to depend upon that which Woodward has solved for the cooling (Annals of Mathematics, Vol. III, 1887, p. 77, eq. 10) of the earth. If for distinction's sake we represent by V_m the temperature of a point in a sheet cooling under the conditions applicable to our eq. (10) above, at a distance (x) from the margin such that x/c is m, and by u_m the temperature of a cooling globe of radius c, cooling under similar conditions—such as those given by Woodward—at a distance from the center of r, such that r/c is m (m being evidently any fraction between 0 and 1), it is easy to transform the two equations so as to show that

$$V_m \quad m\, u_m + (1 - m)\, u_{1-m}$$

Thus $$V_{1/2} \quad u_{1/2}$$

growth, other things being equal, should be more prominent for that mineral that has the lower limits of crystallization.

Furthermore, it is obvious that in proportion as the temperature of the lava when the latter comes to rest is close to the bottom limit of crystallization for a certain mineral, that mineral will be finer grained. Thus a great disparity in the grain of two minerals, greater than could be accounted for by any recourse to chemical reasons, might be accounted for by supposing that the temperature at coming to rest was near the lower limit of crystallization of the finer grained mineral.

Moreover, it is obvious that the conditions of cooling in the amygdaloidal zone will be something quite outside the line of our primary investigation, except that the amygdaloidal zone implies glass, and therefore also that the temperature sank below the glass-forming point before the molten mass could entirely crystallize.

§ 2. Method of observing grain.

So far, although we have assumed that the size of grain depends on the rate of cooling, or more exactly, on the time which passes while the magma is between the temperature at which a given mineral would fuse, and the temperature at which its molecules would solidify as glass, we have not considered how we must measure the size of grain, or whether it is directly proportional to the rate of cooling or to some power of that rate. Now there are two practical ways in which we may measure the size of grains, and one impractical way. First, we may select grains of the average diameter, or, second, cross-sections of average area; or we may take the average bulk, this last method being the impractical way. But if the form of the grains is the same in the coarse as in the fine rocks, the surfaces will be as the squares of any one of the linear dimensions and the volumes as the cubes thereof. Thus in a way the two questions, as to the relation of grain to rate of cooling and the proper method of measuring the grain, run into each other. It may be that the linear dimensions of the grains increase proportionally to the slowness of cooling, in which case it should be to the linear dimensions that we should look for comparisons. If, however, as seems rather more likely, it is the area of the surface of a grain which increases proportionally to the slowness of cooling, since additions are made to the surface, then the area of cross-sections will also be proportional to the slowness of cooling, while if it is really the volume which is proportional to the slowness of cooling, we shall have to cube the average linear dimensions.

Moreover, what gives us the general impression of coarseness of grain is rather the average size of the larger crystals than the average of all. There is then a gap here between theory and fact, that can, so far as I have investigated, be bridged only by an empirical law derived from observations and experiment.

The way I have practically proceeded has been as follows: I have taken three different fields of view in a thin section under the microscope, and have in each field measured the longest diameter (a) of the largest grain of the mineral whose grain I was studying, and also the diameter (ca) at right angles to it.

I have taken the average of the three readings for the mean dimensions m and cm, and then have averaged both, i. e., $\frac{1}{2}$ m (c + 1), and have also multiplied together these mean dimensions (i. e. cm^2). Let us see what the difference will be between the product of the two dimensions and the square of the mean of the two dimensions. The former is cm^2 and the latter is $\frac{1}{4} m^2 (1 + 2c + c^2)$. These two expressions will be the same if c is 1; then as c decreases, the latter expression will become greater. If, for example, c is $\frac{1}{2}$, the ratio will be $\frac{1}{2} : \frac{1}{4} (1 + \frac{1}{2})^2 = 8 : 9$, and if c is 1-6, as sometimes occurs in the feldspar laths, the ratio is 24:49.

§ 3. Effect of cooling on grain, in the augite of the ophites.

We will begin our investigations with the more basic rocks, since they have been artificially imitated by unaided igneous fusion, and we will study first the augite of the ophites, that mineral which both from its texture, and from the fact that it does not occur in porphyritic crystals, has obviously been formed during the period of rest.

Figure 14 shows the results of observations (indicated by small circles) on the Greenstone (Ss. 15245-15258), the vertical scale denoting the thickness in feet, the bottom of the bed being at the bottom of the figure, and the distances on the right of the vertical scale proportional to the area of the augite patches, computed as described in Section 2, in square millimeters. From the point representing the coarsest grain, parabolas are drawn for comparison to the top and the bottom of the bed. It will be seen that the points indicated by the small circles (the crosses and dots are explained below, p. 127) lie parallel to the curve, especially for the bottom part, but they lie uniformly a little below it, indicating a little coarser grain quite down to the margin; that, in other words, there was a small contact zone. If we start the parabola ten feet below the bottom of the sheet, and run it to the center of the sheet, —and it may well be that the coarsest sample taken by us is in

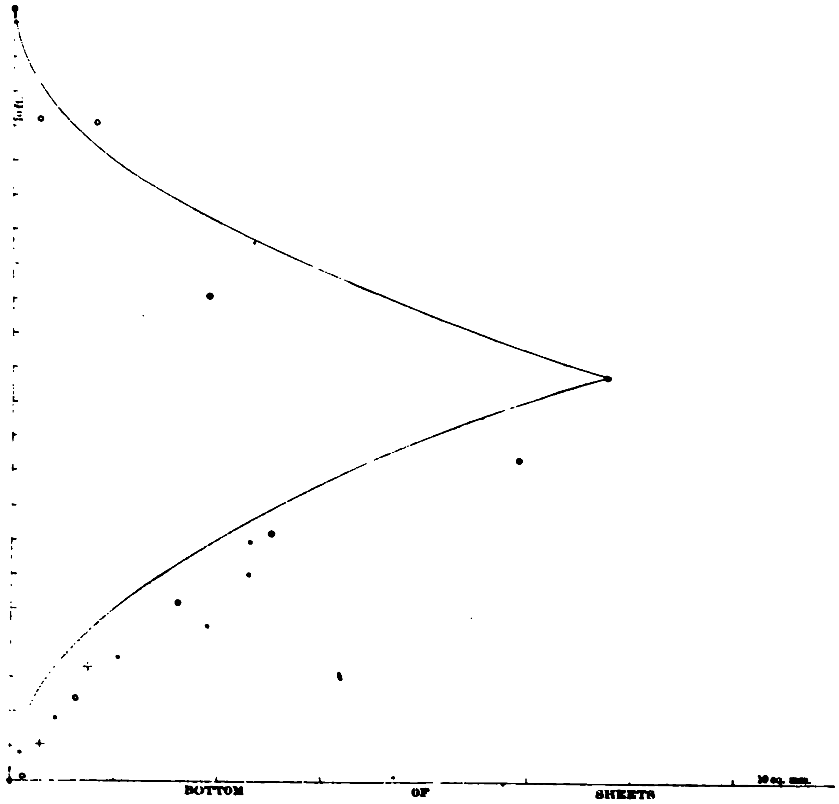

Fig. 14

Illustrates the relation of the area of cross-sections of augite crystals to the distance of the crystals from the bottom of the sheet: different signs indicate observations on specimens from different sheets, as follows:
○ The Greenstone, Drill hole No. VI, 130-363 ft.; Ss. 15248-58.
• Drill hole No. XIV, 202-367 ft.: Ss. 15804-10.
+ Drill hole No. XVI, 696-786 ft.: Ss. 15934-44.

reality a few feet from the coarsest part of the bed—we shall get a curve of even more exact coincidence with the points of observation; both for the grain above, and for that below the middle of the bed. Now these observations indicate a grain increasing in size quite to the center of the bed, with no appreciable zone of uniform grain in the middle, and this remains true whether we compare linear, surface, or volume dimensions. (For if the grain at two points is equal, it will be equal whether we compare it in one way or the other. If, on the other hand, it is unequal, it will remain unequal, the only difference being in the rapidity of the increase from one point to the other.) Such a condition of things indicates a rate of cooling decreasing from the margin even to the center of the sheet, and as we have seen (pp. 110-113), this means that the rock solidified during the very first period of cooling, immediately after coming to rest.

Now let us see if other considerations tend to verify and support this conclusion, or to contradict it.

(1) The observations plotted show not only that the increase in the size of the grains in the bed continues from the margin to the center, but also that this increase, *measured by area of cross-section,* follows a parabola, that is, that the area of the cross-section of the grain varies as the square of the distance of the latter from the margin. A similar law, as we have seen (p. 114), holds for the initial time of cooling, and is thus not only a verification of the conclusion above,—that the rock solidified during the first period of cooling—but leads to the conclusion that *the area of cross-section or surface of the grains varies directly as the slowness of cooling.*

(2) If this be true, the rate of cooling and the size of grain ought to be independent of the size of the sheet, in sheets which have thus solidified before the center had appreciably cooled. The only way in which we can test this law is to compare other ophites of apparently similar composition but different size. In Figure 14 similar observations for the 157* foot flow, drill hole No. XIV, 202 feet to 367 feet (Ss. 15804-15810), are indicated by dots, and those of the 80* foot flow, drill hole No. XVI, 696 feet to 786 feet (Ss. 15943-15944), by stars, and it will be seen that they show a very fair coincidence with the theory. These flows were not chosen to fit, but

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* These figures represent the actual thickness.

because they fill well the requirements as to the varying size. Other observations have also been computed, and harmonize as well as these. In a general way we must say for our ophite flows that, relatively speaking, their solidification took place almost immediately after they came to rest; that they were not superheated, and that the grain, so far, at least, as the augite is concerned, is measurably independent of the size of the flow, but dependent rather on the distance from the margin. And if the areas of the augite sections vary as the squares of their distances from the nearest margin, then the square roots of the areas, or *the linear dimensions of the augite patches are directly as the distance from the margin*; a very simple law, the verification of which by field observations will tend to sustain the law from which it is derived. In Figure 15 we have a diagram showing the average or mean of the greatest dimensions of the augite mottlings for a number of thin sections from the respective bottoms of sheets of ophite, and also the average or mean of the dimension at right angles to this, by straight lines

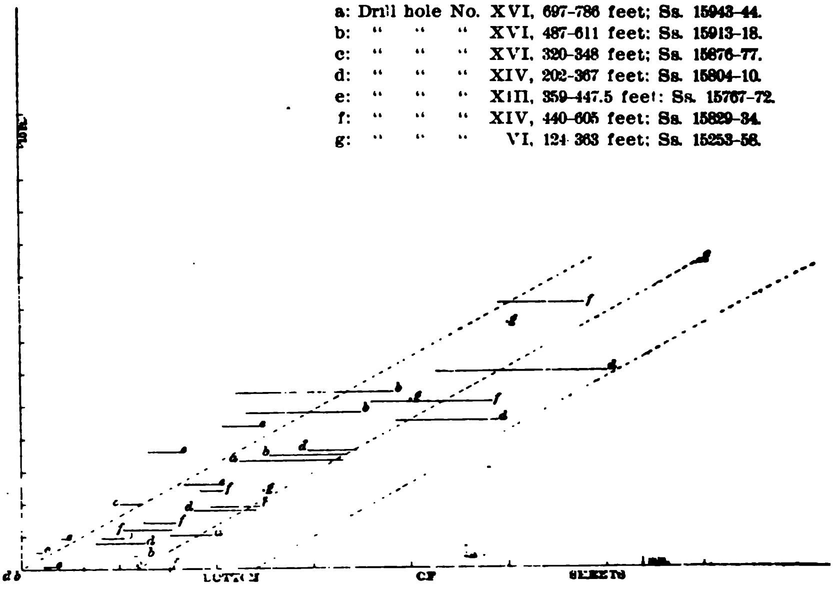

Fig. 15

Illustrates the relation of the linear dimensions of augite crystals to the distance of the latter from the bottom of the sheet, in ophites; letters a, b, c, etc., indicate specimens from different sheets.

drawn at right angles to the scale of thickness, each line connecting two points, which by their respective distances from OA represent the two means above referred to.* The square roots of the respective products of these means, i. e., the quantities which should be in direct ratio to the distances from the margin, will be represented by points below the middle of each line. These latter points ought to lie on one straight line for any one sheet, if the law is strictly true. These points are noted by dots lettered g for the Greenstone. The length of the lines gives some idea of the probable range of error. The tendency to arrangement along a line is evident and, with the exception of e, the rate of increase is not far from that in the Greenstone (and e has some exceptional characters—an unusual amount of feldspar with a glomero-porphyritic tendency). A line from the 7 mm. grain of the Greenstone (at 96 feet from the margin), to the 1.25 mm. grain near the foot wall, will pass close to the intermediate values, will cut most of the lines, and, if we allow for an error of one millimeter in our estimates of grain, will cover practically the grain for all the sheets but e. It will lead to the approximate expression, derived from the equation of a line through two points,

$$y \pm 1 = 0.06\,(x + 1)$$

where y=linear dimensions of grain in mm. and x=distance in feet from margin of bed. Figure 16 covers most of the remaining observations on ophite sheets (apparently undisturbed by slips, with well defined margins) on Isle Royale, even if only in part ophitic, and it will be seen that most of them are covered by the formula above, if we allow as above an error in y of 1 mm. This allowance is necessary in order to offset the small number of observations we have used in obtaining the average dimensions of the augite, to offset the variation in some slight degree in chemical composition, and, what is especially important, to offset the varying amount of contact zone, the grain of the larger sheets like the Greenstone being properly reckonable from the margin of this zone.

Except in the case of the Greenstone we have not given the observations for the upper half of the flows. These observations, however, show the same law, though somewhat more obscurely. The effect of the amygdaloidal zone and magmatic differentiation, and possibly original irregular distribution of temperature is shown in fairly frequent variations from the general law, yet not frequent enough but that the general fact that they follow the same general law can be clearly seen.

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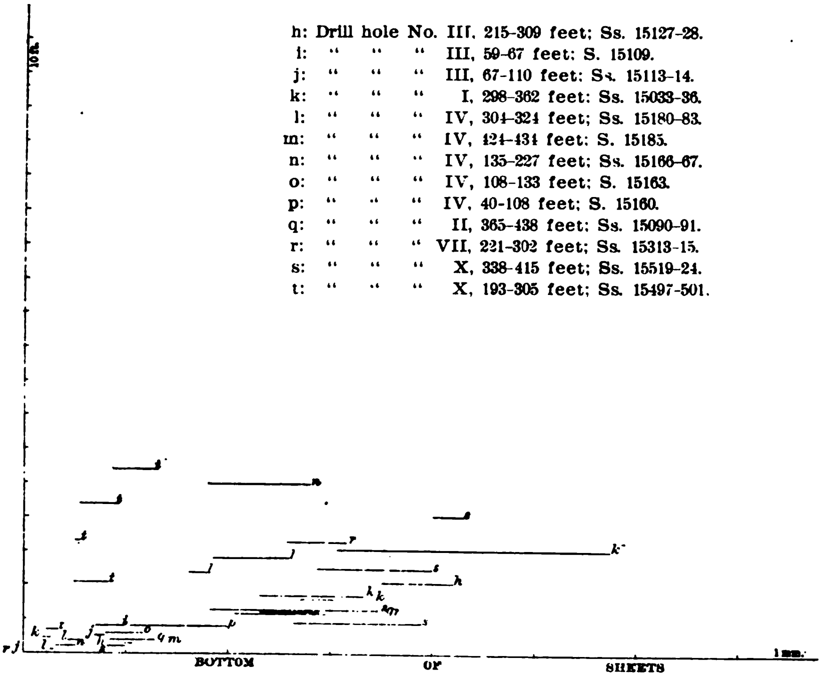
* The lines are lettered with reference to the sheet from which they are derived.



h: Drill hole No. III, 215-309 feet; Ss. 15127-28.
i: " " " III, 59-67 feet; S. 15109.
j: " " " III, 67-110 feet; Ss. 15113-14.
k: " " " I, 298-362 feet; Ss. 15033-36.
l: " " " IV, 304-324 feet; Ss. 15180-83.
m: " " " IV, 424-434 feet; S. 15185.
n: " " " IV, 135-227 feet; Ss. 15166-67.
o: " " " IV, 108-133 feet; S. 15163.
p: " " " IV, 40-108 feet; S. 15160.
q: " " " II, 365-438 feet; Ss. 15090-91.
r: " " " VII, 221-302 feet; Ss. 15313-15.
s: " " " X, 338-415 feet; Ss. 15519-24.
t: " " " X, 193-305 feet; Ss. 15497-501.

FIG. 16

Illustrates the relation of the linear dimensions of augite crystals to the distance of the latter from the bottom of the sheet, in sheets not represented in Fig. 15; letters h to t indicate specimens from different sheets.

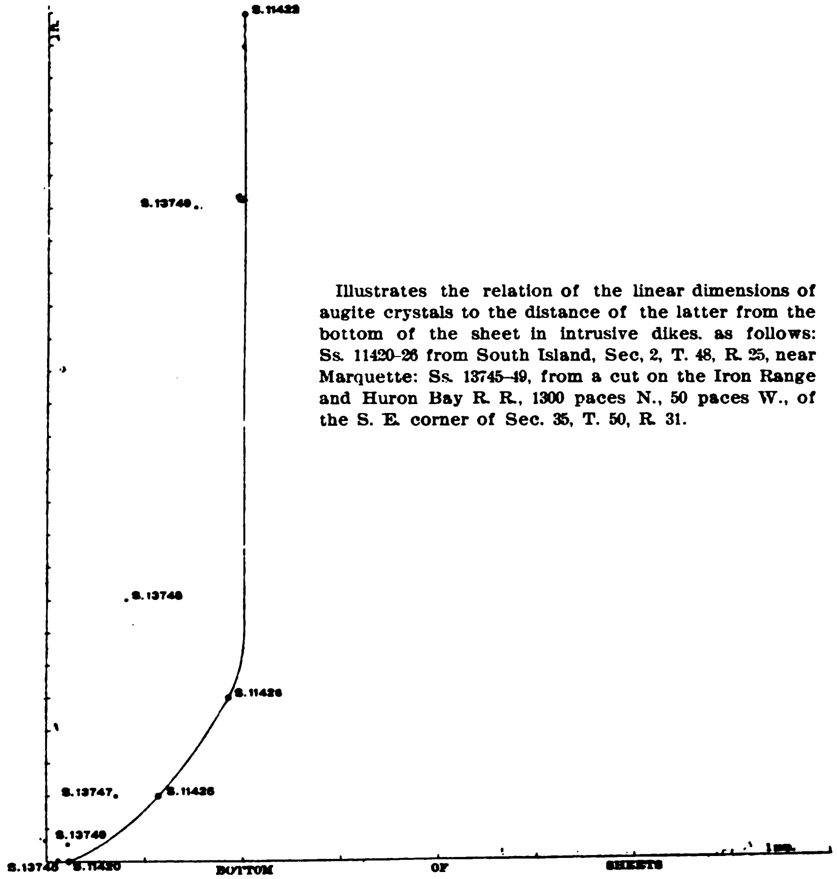
It will be noticed in figure 16, that (Ss. 15489-15501) t cannot be given at all the same rate of increase as the Greenstone, though the increase is still linear. The reason is not far to seek, and this bed was put in only for comparison. The feldspar is mainly andesite (Ab_5 An_3) and the augite is not in ophitic patches, but often in patches of granules, and often much less in quantity. Again, s (Ss. 15513-15523) is another bed with a different feldspar from that of the normal ophites. In fact, a detailed discussion would enable us, for each particular composition, to confine much more closely the limit of variation from the law.

(3) To the conclusion that the solidification of the ophites belongs to the first stage of cooling, the whole magma or molten mass being already nearly down to the temperature of solidification as glass, point not only the above mentioned facts, that the area of the grains increases in the square of the ratio of their distance from the margin, and that the distance from the margin being the same, the grain is measurably independent of the size of the flow, but a farther fact points to the same conclusion, namely, the fact that we have right near the middle of the Greenstone, in S. 15253, a big porphyritic crystal of feldspar (somewhat more basic, to be sure, than the usual feldspar), for, according to Fouqué and Lévy (Synthèse des Minéraux et des Roches, p. 74) it is only within a narrow range of temperature that the crystallization of feldspar will take place while the augite is still molten.

(4) There are a number of other reasons, in the variation in grain of any one constituent and in the relative grain of different constituents (cf. § 6), for believing that the Greenstone is a flow and not an intrusion; and also in its general stratigraphic relations, i. e., its appearance uniformly at a given horizon in the series, its great lateral extent, its slight metamorphism of the underlying conglomerate, etc., etc. Now if it is a far- and wide-spreading flow, we should expect it to have continued in motion until it was so far cooled as to become viscous and to be on the point of stiffening, in which case the solidification must have followed immediately after it came to rest, a conclusion in harmony with our previous arguments.

(5) As we have spoken of intrusions, it will be interesting to compare the curve of the grain, Fig. 15, with that of an undoubted intrusion. We give, therefore, in Fig. 17, corresponding curves for two dikes, one of which (Ss. 11421-11426, near Marquette in the Huronian) is, as nearly as can be judged petrographically, of similar composition to the ophites. We see at a glance that the curve is of an entirely different type, and no change in measuring the dimensions can make it similar. The belt of uniform grain in the middle must remain uniform, however we measure the grain. In this respect it is more like a plutonic rock. The decrease in size of grain toward the margin shows that the dike was injected into comparatively cold rocks. There is no indication here of as much

contact effect as in the much larger Greenstone. But the curve of this dike can be matched by a curve, Plate IV, curve F, which shows the rate of cooling sometime after the cooling has begun, so that the temperature has dropped about half way. Hence we may conclude that this dike had considerably more than the temperature of crystallization of augite when the dike came to rest;



Illustrates the relation of the linear dimensions of augite crystals to the distance of the latter from the bottom of the sheet in intrusive dikes. as follows: Ss. 11420-26 from South Island, Sec, 2, T. 48, R. 25, near Marquette: Ss. 13745-49, from a cut on the Iron Range and Huron Bay R. R., 1300 paces N., 50 paces W., of the S. E. corner of Sec. 35, T. 50, R. 31.

Fig. 17

this might well have been the case, for we know that lavas sometimes attain temperatures of over 1200° C. We can even estimate from the shape of the curve the ratio of the initial temperature to the temperature of crystallization of augite.

(6) Farther verification of our conclusions will come, if we find that the grain of the other minerals is in accord with the conditions of cooling indicated by the grain of the augite.

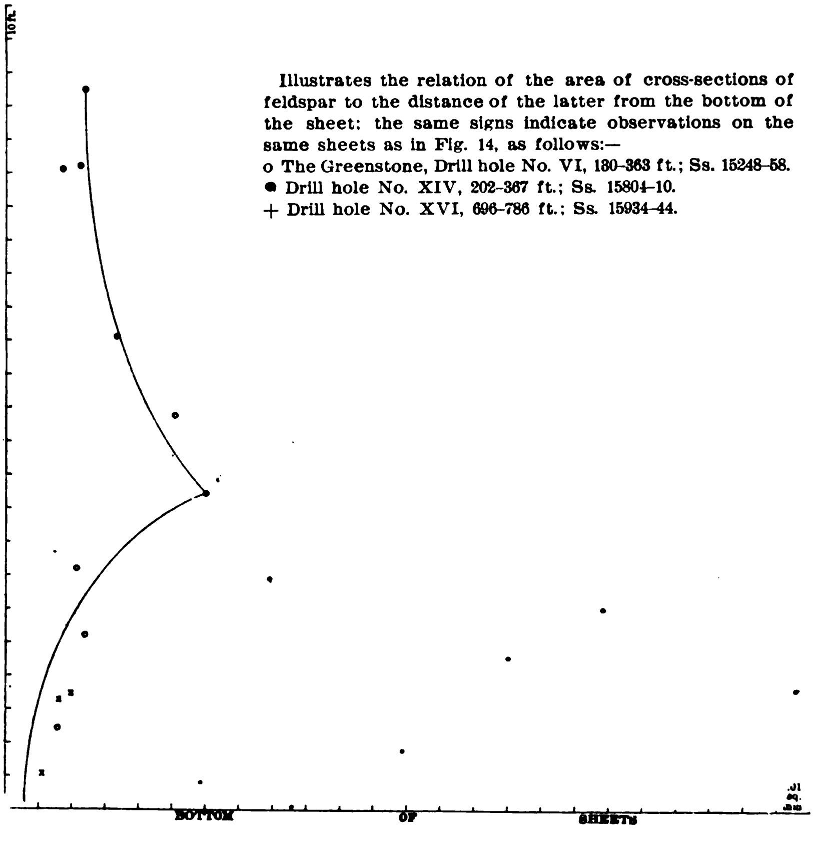
§ 4. Effect of cooling on grain, in the feldspar of the ophites.

In Fig. 18 we have represented the grain of the feldspar in the same sheets as were represented in Fig. 14, and the same symbols are used. The only difference is that the scales for the size of grain vary as indicated in the figures, and the comparative parabolas in Fig. 18 are drawn to indicate an appreciable size of grains at the margin, for we find, as a matter of fact, that even close to the margins, both upper and lower, the feldspar has an appreciable size. The rock in fact has a porphyritic texture. The cause of this appreciable size at the margin is not, as in the augite, to be ascribed to a contact zone so much as to the fact that the feldspar began to crystallize before the lava stopped flowing, i. e., before the period of rest. This fact is, of course, indicated in all cases where we can detect traces of a fluidal arrangement in the feldspar.

We must, therefore, subtract from the size of the feldspar whatever size it may have attained before the sheet came to rest, and even then the presence of so much pre-crystallized feldspar might seriously affect the law of grain. However, the generally concave curve is plainly enough indicated in two of the sheets. In the other one there is the utmost irregularity, the difficulty being that the sheet is markedly porphyritic at the margin, and the feldspar tends to be glomero-porphyritic by collecting in nests, so that the separation of the older and younger feldspar, and the estimation of their respective sizes is in this case unsuccessful. In general, the feldspar laths are so narrow, so fond of attaching themselves to each other by the side (pinacoidal), that it is a matter of difficulty to get accordant results.

Comparing the feldspar and the augite of the Greenstone, we get some significant results.

Below the center of the sheet there is more of a tendency for the grain of the augite to exceed, and for the feldspar to fall below the theoretical curve, while above the center the feldspar is markedly larger, and the augite falls short. This reciprocal relation is more strikingly brought out in specimens 15250 and 15249, the former abnormally augitic, the latter abnormally feldspathic—the two in reciprocal relation. These specimens correspond respectively to the dark and light types of diorites (Pumpelly's gabbro) which Marvine distinguishes in this very flow (Geol. Sur. Mich., I, Pt. II, pp. 133-136). As he says, they occur in alternating bands, sometimes but a few inches thick, and not sharply separated. I am convinced that they represent a magmatic segregation or differentiation of some kind, or an original lack of homogeneity. If we suppose a tendency of the feldspar or feldspar molecules to rise toward the top of the sheet and of the augite substance to settle, and imagine the layers to be stirred and interkneaded in the process of the flow, we shall frame a hypothesis which will account



Illustrates the relation of the area of cross-sections of feldspar to the distance of the latter from the bottom of the sheet: the same signs indicate observations on the same sheets as in Fig. 14, as follows:—

o The Greenstone, Drill hole No. VI, 130-363 ft.; Ss. 15248-58.
● Drill hole No. XIV, 202-367 ft.; Ss. 15804-10.
+ Drill hole No. XVI, 696-786 ft.; Ss. 15934-44.

Fig. 18

for all the phenomena. For the present, however, our chief object is to point out the indication of another law than that of cooling, namely, that of chemical composition, as influencing the size of the grain. So long as the composition of the flow is tolerably homogeneous this factor can be but of minor importance, but in flows of varying composition its influence may be large, and remains to be investigated. See the discussion of the analyses of specimens 15515, 15519 and 15523, and compare in Fig. 16 the grain of the sheet from which the material for these analyses came.

§ 5. Grain of other constituents of ophites.

When we come to the remaining original and important ingredients, aside from the augite and the feldspar, we find the determination of grain more and more difficult. In the first place, with one or two exceptions (Ss. 15827 and 15807), the olivine is all altered to serpentine or at times to that reddish micaceous substance, which has been often described (Ros. Mik. Phys. 1896, II, p. 963), and is at least akin to Lawson's iddingsite. This alteration does not make it by any means always impossible to recognize the olivine outlines, but it does make it hard always to be sure that we are rightly drawing the line between olivine and augite, and renders it very frequently uncertain whether a given patch of serpentine represents more than one olivine grain.

With the iron oxides we have similar difficulties. They occur replacing the olivine, sometimes secondary, and sometimes apparently not, at any rate making up together a unit, so far as grain is concerned. Moreover, being opaque and isotropic, it is not possible to distinguish with any certainty granular aggregates, twinned aggregates, and allotriomorphic forms. But making all allowance for greater uncertainty in observations on these minerals, some things seem reasonably certain. The laws can be made very obscure by statistics, and general impressions gathered from observation of the sections must supplement them.

In the first place then, there is ample evidence of the formation of the olivine at an early day before the augite and feldspar, that is, before the period of rest. In many cases it appears to have been corroded. It is porphyritic and of noteworthy size, therefore, even up to the margin, both at top and at bottom. Then in the more augitic and olivinitic flows, as for example, specimens 15820 to

15834, there is a tendency for the grain of the olivine to increase for some distance, though interrupted by variations, and then to decrease toward the top of the flow, but in the more feldspathic flows, in which the ophitic texture is confined to the lower part of the flow, the variation in the grain of the olivine bears only a very complex relation, if any, to its distance from the margin, as is illustrated for example by specimens 15489 to 15501. Right in the middle of the sheet the olivine is often exceptionally small in some parts and large in others. The places where it is large are the coarse feldspathic spots with a doleritic texture. There are evidently other laws more influential upon its grain, than those of cooling.

In review then, we may say that in the ophites the augite, the last mineral formed, shows by its size of grain the effect almost exclusively of cooling, and conforms to the laws of initial cooling from a uniform temperature (pp. 111-112); that all the other minerals appear to have been previously formed or in process of formation and show only faint traces of those laws, but that their grain and appearance and the stratigraphic evidence are quite consistent with the hypothesis that the lava was cooled down almost to solidification before it came to rest.

§ 6. Verification on the Greenstone elsewhere.

Of course the ultimate test of these theories, as of all theories, must be verification. If in other ophites of similar composition and similar variations in grain we shall prophesy their thickness and their effusive character, from size and variation of the grain, and farther investigation shall establish our prophesies to be conformable to the facts, every such case will strengthen our faith in the theory and widen the sphere of its application. To begin with, let us apply the theory to the flow on Keweenaw Point, which we have supposed to be the same as the Greenstone of Isle Royale. In Marvine's description of this bed (Geol. Sur. Mich., I, Pt. II, pp. 133-136) the gradual increase in grain down from the top and up from the bottom is clearly stated, until the bed begins to break up into lighter and darker, respectively more feldspathic and more augitic layers. From that point it is harder to trace the grain, either in the field or in his descriptions, and exact indications of size of grains are wanting, but the statement that lustre mottlings toward the top of bed No. 108 (the lowest 412 feet of the Greenstone), "often over the space of nearly two inches square, all catch and reflect the light simultaneously," would certainly indicate that the patches of ophitic augite (which Marvine calls hornblende) were on the average over an inch, i. e., more than 25 mm. in diameter. Or, substituting in the formula of p. 129* 25 ± = 0.06 x + 1, where x denotes distance from margin; therefore distance from margin is 400 ±, —a sufficiently near coincidence.

On the road from the Central mine on Keweenaw Point to Copper Falls, I found the mottling in the Greenstone as coarse as six knobs to the foot, or about 50 mm, which would indicate by the same rule a point about 800 feet from the margin, or a bed 1600 feet thick more or less, a result in agreement with the facts so far as I know them. (See Part II.) Again, samples from Marvine's bed No. 91 (exposure up on the hill) give mottlings from two-tenths to three-tenths of an inch, indicating a distance from the margin of 80 to 120 feet. Marvine's bed No. 93 seems to be still coarser, with a mottling 1.5 in. x 0.8 in., etc., that would indicate a distance from the margin of over 400 feet; whereas it really is only about 200 feet. The point where the specimen showing the mottlings was taken is in the part of the bed where the light and dark types alternate.

Marvine's bed No. 96 has weathering knobs of about an inch in diameter with mottlings showing a length of 0.6 inch, thus indicating a distance from the margin of 300 feet to 400 feet. A large sample from the Greenstone, whose exact location is unknown, has an average grain of 1.07 in. x 0.75 in., indicating a distance from the margin of 360 feet, and a total thickness of over 720 feet.

Above the Phœnix mine, along the horsepath, I noticed the grain increase at the crest of the range to about two knobs to the inch. This is at a point about 100 feet above and 400 feet northwest from the bottom of the flow, or about 265 feet vertically above the foot of the bed, the dip being about 26°. The grain would indicate a distance from the margin of about 200 feet.

The general agreement in the cases above cited is as good as one could expect from the rough character of the observations, with the exception of perhaps those at Marvine's bed No. 93.

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* Which we may also write for rough, naked-eye observations, 400 × (size of mottlings in inches) = distance from margin in feet.

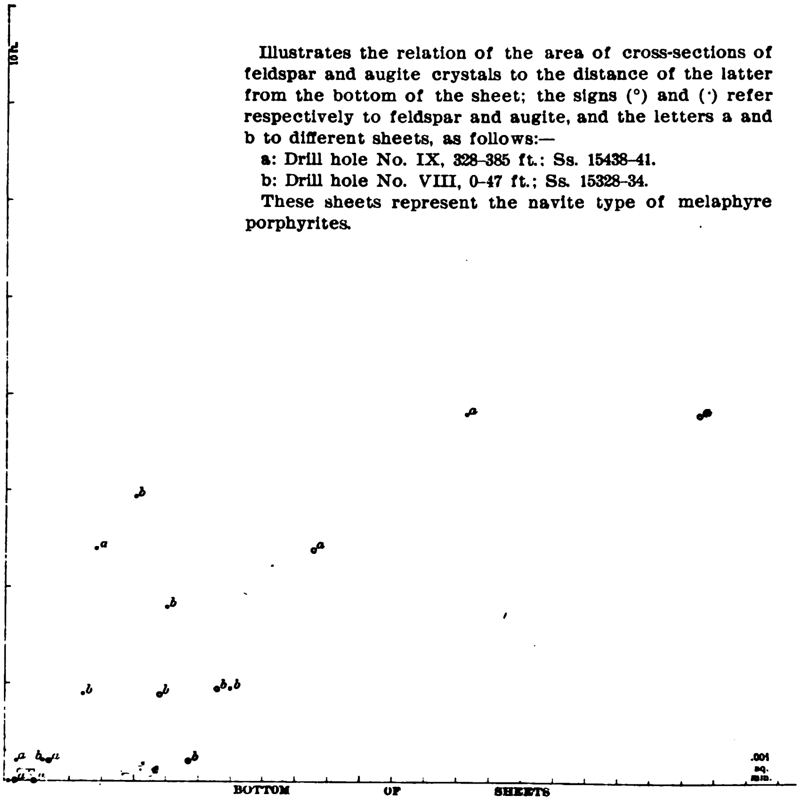
Turning to Irving's "Copper-Bearing Rocks," at page 42 we find lustre mottlings described in a "gabbro," which we have already mentioned as a possible equivalent of the Greenstone, with "brassy diallage faces which are often as much as two inches across," which would point to a bed probably not less than 1600 feet thick (possibly not intrusive but effusive). So, also, the rock illustrated in Plate IX, of the same work, should come from a sheet at a point not less than 90 feet from its margin; if it is comparable to the Greenstone, more probably 110 feet. We have no data at present to show whether these deductions correspond with the facts.

§ 7. Relative size of various constituents.

Before we leave the ophites to consider the possibility of tracing the effect of cooling in other rocks, we have one other point to consider. We have discussed the grain of each constituent, but we have not discussed the relative sizes of the various constituents. These are not capable of being well expressed on the same scale in one diagram,—the difference is so very great,—but we can observe that in the augite diagram, Fig. 14, the scale for the grain in areas is from 1:25 to 1:50, as compared with that for the feldspar areas in Fig. 18. A corresponding linear ratio would be from 1:5 to 1:7. But while the ratio of the area of the feldspar to that of the augite is to be measured in hundredths, for the Greenstone and its immediate allies, it is by no means necessarily true of all ophitic sheets. Take, for example, the sheet from drill hole No. X, 338 feet to 415 feet. The feldspar here is, to be sure, markedly porphyritic, but the general analysis of the rock does not indicate any more feldspathic material than does Foster and Whitney's old analysis of the Greenstone (F. & W. II, p. 88). But taking all the feldspar in the bed, without trying to separate out the porphyritic portion, the grain is very much coarser than in the Greenstone. Toward the bottoms of the two flows, moreover, there is no essential difference in the optical character of the two feldspars, so that it seems quite likely that the reason for the relative smallness of the feldspars in the Greenstone lies in the fact that the sheet did not cool enough in transit to produce any appreciable amount of porphyritic crystals, for they occur only sparingly, and when it finally came to rest, since the temperature of solidification is somewhat higher for the feldspar than for augite, the feldspar had to form even more rapidly than the augite did. Whether this be the true explanation or not, the fact that the feldspar is very much smaller than the augite is another fact quite in harmony with what we have concluded to be the conditions of cooling of the Greenstone (p. 131).

In the dikes cutting the Huronian, already alluded to (p. 131), the feldspar and augite are much more nearly of the same size, although the mineral composition appears to be about the same, and this is what we should expect.

§ 8. Effect of cooling on grain in the more feldspathic rocks.



Illustrates the relation of the area of cross-sections of feldspar and augite crystals to the distance of the latter from the bottom of the sheet; the signs (°) and (·) refer respectively to feldspar and augite, and the letters a and b to different sheets, as follows:—

a: Drill hole No. IX, 328–385 ft.; Ss. 15438–41.

b: Drill hole No. VIII, 0–47 ft.; Ss. 15328–34.

These sheets represent the navite type of melaphyre porphyrites.

Fig. 19

Leaving the ophites, and coming to more feldspathic rocks, we have a number of types to distinguish, illustrated by figures.

(1) In the first type, Fig. 19, which is that of a navite, the melaphyre porphyrite or ashbed diabase of Pumpelly, a very large amount of feldspar was formed in the porphyritic stage. The augite is no longer so markedly coarser in grain than the feldspar, though it is practically impossible to separate the feldspar formed before the sheet came to rest from that formed later. The dimensions of the augite are much smaller than in the ophites, and smaller than the porphyritic feldspars. Both the porphyritic feldspars and the augite increase to a maximum, without any middle zone of even grain.

At the bottom of drill hole No. XIII are some beds which in some respects resemble the first type (for in them there are two

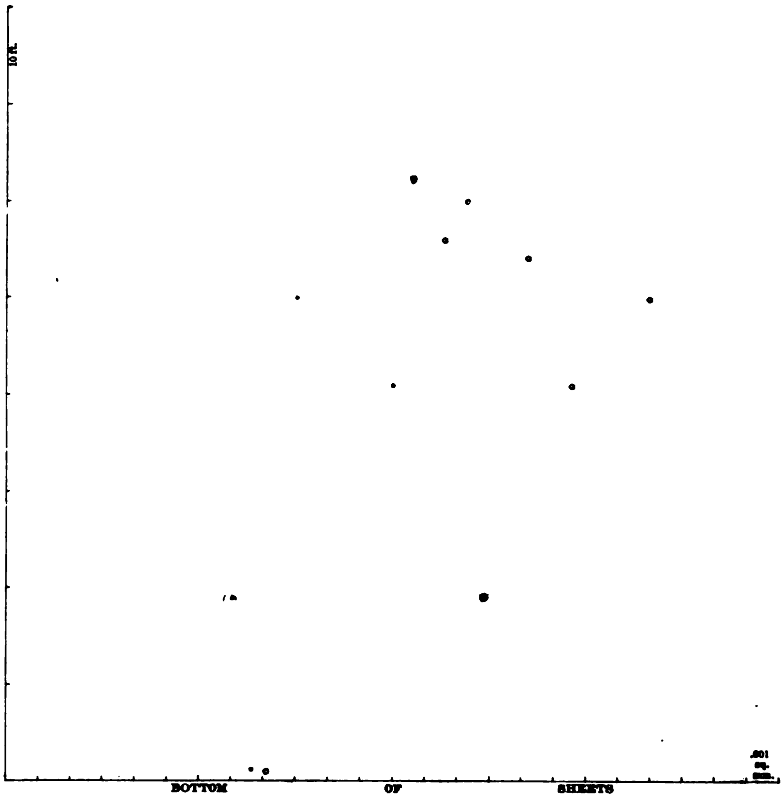


Fig. 20

Illustrates the relation of the area of cross-sections of feldspar and augite crystals to the distance of the latter from the bottom of the sheet, in the Huginnin porphyrite, Drill hole No. XIV, 367–436 ft.; Ss. 15814–19; the signs (°) and (·) refer respectively to the feldspar and augite.

ill-defined generations of feldspar), but are distinguished by a greater abundance of olivine and augite, and by the fact that both these latter show a tendency to occur in two generations. The bottom of these beds is not certainly known, and they are traversed by a fissure vein, but for the first fifteen feet from the top anyway, there is a distinct tendency in the various constituents to become coarser. It is like the previous groups in that the augite is, if anything, smaller than the feldspar.

(2) In the second type, Fig. 20, that of the Huginnin porphyrite, the augite is still more reduced in size, the amount of the feldspar being larger. The increase in size of grain from the margin is slight but perceptible, while the fineness of the grain exaggerates the errors due to imperfect averages.

There are very regularly porphyritic crystals, but they have nothing to do with those of the groundmass, being more than tenfold longer, much broader in proportion, and of a different chemical composition, whereas in the previous type the porphyritic crystals and those of the groundmass were inseparably linked together, grading into each other in size, while the average grain of both increases steadily toward the center.

The next diagram, Fig. 21, represents the grain for the two Minong beds combined, since the dividing line is not very certain. It will be noticed that the scale for the augite areas is to that of the feldspar as 1:10, so that in the coarsest part the augite is really a good deal larger than the feldspar, though by no means so much so as in the normal ophites, and the rock has a really ophitic texture. In the upper part of the flow this texture disappears. It will also be noticed that in the two holes where these beds were cut, they have the same degree of coarseness, so far as the augite is concerned, and the figures for the feldspar agree very well.

In the upper flow there is no certainly identifiable augite and the feldspar is practically uniform in size. The upper flow, as we have remarked, is more of a felsite, and the variation in grain is much less perceptible.

In the felsite at the very bottom of the column, there is some poikilitic quartz, which is probably secondary. The grain is otherwise very fine, and remains very fine for the eighty feet or so that this bed was penetrated.

§ 9. Summary.

Thus we finish the examination of the variation of grain with reference to rate of cooling. Gathering up what we have learned, we find:

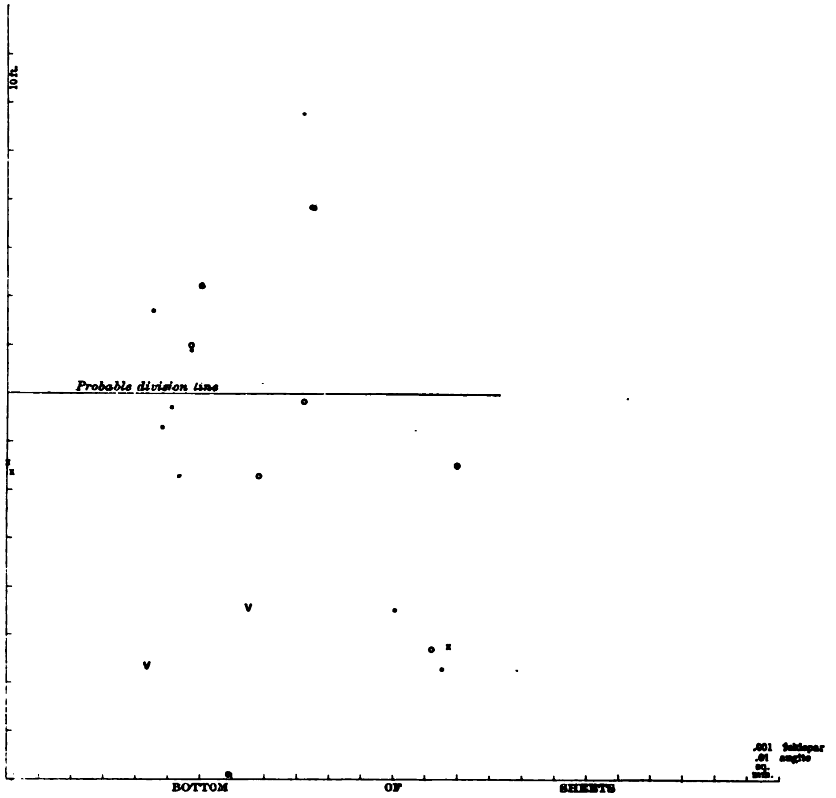


Fig. 21

Illustrates the relation of the area of cross-sections of feldspar and augite crystals to the distance of the latter from the bottom of the sheet, in the Minong trap and porphyrite; different signs indicate the various observations, as follows:—
● Feldspar, in Drill hole No. I, 426-536 ft.; Ss. 15044-54.
v Augite, in the same flow.
o Feldspar, in Drill hole No. III, 100-415 ft.; Ss. 15116-28.
x Augite, in the same flow.

(1) The relation of grain to distance from margin, and its correspondence with the laws of cooling, are most conspicuous in the augite of the highly augitic rocks, and less marked in oligoclase and in the porphyrites.

(2) The flows of Isle Royale show a grain increasing markedly up to the very center of the sheets, as is to be expected in sheets

which stopped flowing only when near the temperature of consolidation.

(3) The relative grain of different minerals shows little or no connection with the distance from margin, nor with the laws of cooling.

(4) The effect of the laws of cooling cannot always be traced in the porphyritic crystals, but sometimes crystals, which began to form before the cessation of motion, continued at the center to grow uninterruptedly thereafter, so that while two generations can be distinguished at the margin only one can be observed at the center.

§ 10. Effect of chemical composition on grain.

The effects of chemical composition on grain have already been brought out incidentally in discussing the laws of cooling, for they appear as modifying these laws. Gathering these scattered observations together (p. 133 and the various diagrams), we have an almost self-evident law, to wit:

Other things being equal, the greater the abundance of its constituent molecules the coarser the grain of any mineral.

This may farther be illustrated in two ways:

(1.) In the case of a single flow like that from drill hole No. X, 338 feet to 415 feet (Ss. 15513 to 15524), we find a greater abundance of augite at the bottom of the bed. This is indicated by the analyses, by Mr. F. P. Burrall,[*] which may be separated with more or less probability into constituent molecules as I have done just be-

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DR. L. L. HUBBARD, [*] MARCH 2, 1896.
State Geologist, Houghton, Michigan.

DEAR SIR:—The specimens submitted to me for analysis during the month of February gave the following analyses:

	No. 15515.	No. 15519.	No. 15523.
SiO_2	46.45	46.25	46.13
Al_2O_3	16.60	18.39	19.79
Fe_2O_3	2.72	7.70	7.24
FeO	7.25	3.52	3.79
†CaO	6.32	12.19	11.43
MgO	9.21	4.65	7.27
K_2O	1.02	1.04	0.52
Na_2O	4.05	3.76	2.55
CO_2	0.40	1.00	0.29
H_2O	5.01	3.41	1.83
Totals	99.03	101.91	100.84

† In each case the MnO was weighed with CaO and not separated. In no case would MnO run over 0.1%. All three rocks melted over Bunsen blast lamp quite easily and formed a black glassy globule. They all seemed to melt with equal ease.

Very respectfully,
(Signed) FREDERICK P. BURRALL.

low. These considerations agree with direct observation of the thin sections in indicating an increase of augite as we approach the bottom of the bed. Now Fig. 22 shows that the grain of the augite in the lower and more augitic part of the flow is larger than would be expected under the laws of cooling and smaller in the upper part of the flow. We have called attention to a slight indication of the same thing in the Greenstone diagram, Fig. 14. It is obvious also, in the Minong trap, Fig. 21. But a general study of the thin sections indicates more distinctly than any diagrams that this tendency for a bed to be, *pari passu*, more augitic and coarser at the bottom than at the top, is very general.

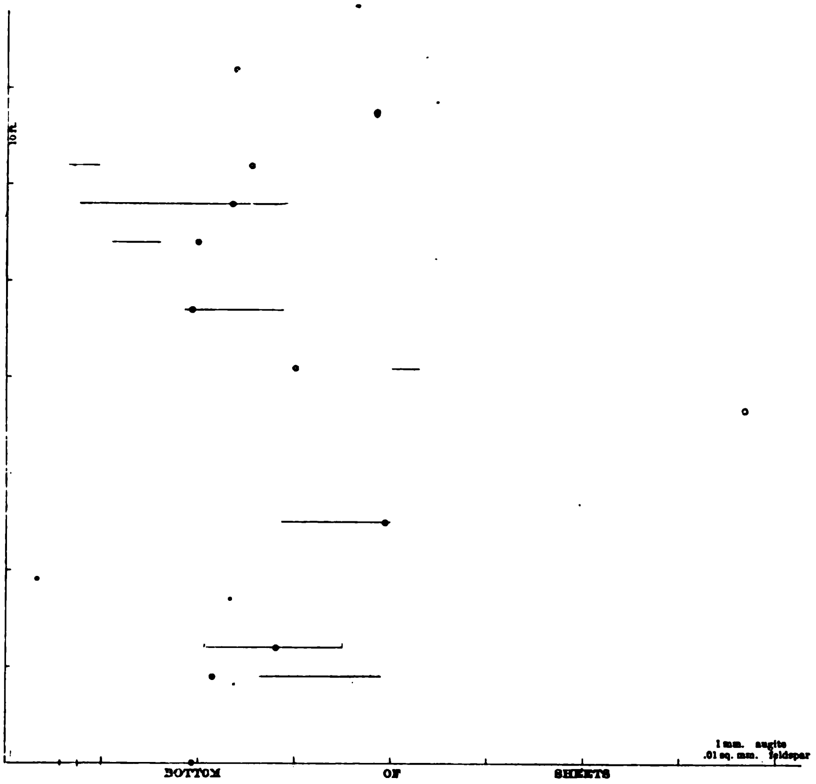

Fig. 22

Illustrates the relation of the area of cross-sections of feldspar (o) and augite-crystals to the distance of the latter from the bottom of the sheet, in the sheet that has been analyzed:—
S. 15523 at 9 ft., S. 15519 at 41 ft. and S. 15515 at 62 ft., respectively, from the bottom of Drill hole No. X, 338-415 ft.; Ss. 15513-24.

Pumpelly's analyses of bed 87 (IX and X at the end of Chapter IX) indicate the same thing, though his specimens were much altered.

On pages 146 and 147, in dividing up the analyses of Nos. 15515 and 15523 into the probable constituent molecules of the original rocks, I have neglected the water and the CO_2, as they can be easily accounted for afterwards by turning the molecules into their hydrated forms as they appear in serpentines, chlorite, etc. Of course such a division is ideal. The Fe and Mg replace each other in all the molecules in which they appear, but that makes no material difference in the relative proportions of the constituent minerals. It would only change them slightly in composition, the olivine being less ferruginous and the augite more so. Of more importance is the K_2O. It is uncertain whether originally it occurred in a feldspar molecule absorbing SiO_2, or with part of the olivine molecule making biotite, as I have figured it, or entered, as is not at all impossible, into augite, or was in the residual glass, or irregularly divided among these various molecules. In any case it is likely to absorb an equal molecular proportion of Al_2O_3. There will be a varying amount of SiO_2 thus used which will imply a correspondingly varying proportion of olivine and augite. A much greater cause of uncertainty is the iron, which is liable to have changed its state of oxidation, and may have occurred originally either in the augite, the olivine, or by itself, and leaves quite a chance for different interpretations, the only thing practically certain being that alkaline feldspar *and the olivine* decrease toward the bottom, while the augite increases.

(2.) The second application of this rule is to different flows. If we compare the dimensions of the augite in the Greenstone and its congeners as exhibited in Figs. 15 and 16, first with the grain of the augite in Ss. 15497-15501 (t in Fig. 16), then with the Minong trap, Fig. 21, and then with the porphyrites of Fig. 19, we see distinctly the lower gradient of increase of the augite in the less augitic rocks, the augite in the Minong trap being, relatively to position, about half the size of the Greenstone augite, that in the porphyrites nearer the thirtieth. Even in such a sheet as that from which come Ss. 15762-15772 (e), which is ophitic throughout, though recognized as less augitic than usual, the falling off in the gradient or rate of increase of grain is distinct. The numerical formula given on page 129

Molecules (1).	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	K_2O	Na_2O	CO_2	H_2O	Corresponding percentage.	
Equivalent weight (2)	60	102	160	72	40	56	94	62	44	18		
Per cent in analysis of 15515 (3)	46.45	16.60	2.72	7.25	9.21	6.32	1.02	4.05	0.40	5.01	99.03	
(3) ÷ 2	0.774	0.163	0 017	0.101	0.230	0.113	0.011	0.065	0.009	0.278		
Feldspar											4.03	
Ab Na_2O, Al_2O_3, 6 SiO_2, using all Na_2O	0.390	0.065						0.065			6.62 23.4	
	0.384	0.098										34.06% Ab
An 2 CaO, 2 Al_2O_3, 4 SiO_2	0.130	0.065				0.065					3.64	
Enough for Ab_2An_1, chap. VI. § 2.											6.62 7.8	52.13% Ab_2 An_1.
	0.254	0.033				0.048					1.08	18.07% An
K_2O, Al_2O_3, 2 SiO_2: may combine with Ol. molecule for biotite or with 4 SiO_2 for feldspar	0.022	0.011					0.011				1.12 1.32	
	0.232	0.022									1.58 2.24 1.32	3.47% requiring 2.6% SiO_2 to make orthoclase or any amount of olivine for biotite.
*FeO, Al_2O_3, SiO_2, using the remainder of Al_2O_3	0.022	0.022		0.022							1.22 2.72	5.14%
	0.210	0.000		0.079								3.94% Magnetite
FeO, Fe_2O_3			0.017	0.017							2.668	15.49% augite.
				0.062							1.92 5.76	
CaO, MgO, 2 SiO_2; augite, diopside, using all Ca	0.096				0.048	0.048						10.35%
	0.114				0.182						7.28 5.46	
Balance so far as may be is 2 MgO, SiO_2	0.091				0.182						3.32	12.74%
Respectively 2 FeO, SiO_2	0.023 0.023										1.38	17.44% Olivine.
				0.046								4.70%
Excess of bases				0.016							1.15% FeO not accounted for.	

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* Augite-fassaite molecule.

Molecules (1)	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	K_2O	Na_2O	CO_2	H_2O	Sum.	Sp. Wt.	Corresponding percentage.
Equivalent weight (2)	60	102	160	72	40	56	94	62	44	18			
Per cent in analysis of S. 15523.	46 13	19.79	7.24	3.79	7.27	11.43	0.52	2.55	0.29	1.83	100.84	2 887	
(3) + (2)	0.769	0.194	0.045	0.053	0.182	0.204	0.006	0.011	0.007	0.102			
Ab = Na_2O, Al_2O_3, 6 SiO_2, using all Na_2O	0.246	0.041						0.041					2.54 4.18 14.76
	0.523	0.153											21.48 % Ab
An = 2 CaO, 2 Al_2O_3, 4 SiO_2, enough for $Ab_2 An_3$, chap. VI, §2	0.246	0 123				0.123							6.89 12.54 14.76 — 55.67 % feldspar $Ab_2 An_3$
	0.277	0.030				0.081							34.19 % An
K_2O, Al_2O_3, 2 SiO_2; may combine with 4 SiO_2 for feldspar or with olivine molecule for biotite	0.012	0.006					0.006						0.55 — 0.03 0.61 0.72
	0.265	0.024											1.87 %. Query: In orthoclase or biotite molecule?
FeO, Al_2O_3, SiO_2; the augite fassaite molecule, using the remaining Al_2O_3	0.024	0.024		0.024									1.73 2.45 1.44
	0.241			0.027									5.62 %
CaO, MgO, 2 SiO_2; the augite diopside molecule, using all remaining CaO	0.162				0.081	0.081							4.54 3.24 9.72
	0.079				0.101								19.50 %
FeO, Fe_2O_3; magnetite, using all remaining FeO			0.029	0.029									2.08 4.64
			0.016										6.72 % magnetite.
MgO, Fe_2O_3, SiO_2; augite molecules, using all remaining Fe_2O_3	0.016		0.016		0.016								0.64 2.56 0.96
	0.063				0.085								4.16 % 27.28 % augite.
2 MgO, SiO_2; olivine molecule, using remaining MgO	0.043												3.44 2.58
SiO_2 excess; in feldspar, or in converting olivine to augite	0.020				0.085								6.02 % olivine. 1 20 SiO_2 not accounted for.

With all allowances for interchange of bases and secondary alteration, the relative constancy in quantity by variability in chemical character of the feldspar, the increase in the augite and diminution of olivine as compared with 15515 are clearly indicated. See note. p. 148.

must not then be applied indiscriminately, but only to the Greenstone and to flows strictly comparable. As we have seen, it does apply fairly well to a large number of other flows among the Keweenaw beds and may thus be considered as characteristic of a standard type, so that variation from it points to abnormal chemical composition. Numerous instances of the smaller grain of the augite have been noted, from actual measurement, in the beds above the Greenstone.

§ 11. Other factors affecting grain.

We have mentioned that there are other factors affecting grain, just as there are other factors affecting the rate of solidification. But our investigations throw little light on them. We have no right to presume any great variation in pressure in the series which we have been studying. The sole exception which we have already mentioned, is that around certain amygdules the grain seems to be finer (Pl. VI, Ss. 15811 and 15008-15117). This can hardly be due to cooling, as the escape of heat into a small closed space like the bubble in which an amygdule is formed, can hardly be more rapid than elsewhere, but this finer grain may easily be supposed to be due to the escape of the gas that caused the bubble. Thus, too, we have around an amygdule in S. 15618, a zone with a trichitic texture of arborescent feldspar. Since, as we have already mentioned, the diffusion of gas follows in general the same laws as the diffusion of heat, and indeed is dependent upon it, our best chance of studying the varying effects of gas diffusion, would be if we

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In the table on the preceding page the CO_2 and H_2O are neglected as secondary additions. The excess of bases in Sp. 15515, 1.15 per cent FeO not accounted for, points to a probable removal of part of the SiO_2 which has been replaced by the CO_2 and H_2O. It would be mathematically easy enough but not physically probable to assume that the iron was added to the augite so as to make a kalk-olivine. Or it is likely that somewhat too much An has been taken, as the determination, by the extinction angles, of ratio of Ab : An may easily be 10 per cent out. Finally, it is obvious by comparison with analysis of No. 15523, that the relative proportion of Fe_2O_3 : FeO is liable to variation which may be due to the character of the secondary alteration. Molecule (3) was very likely in the original glass with SiO_2, now removed. The FeO and MgO are interchangeable in (4) and (7), making a possible variation in percentage there. Query: Is the higher percentage of iron in the olivine in No. 15515 probable, or is it more likely that the iron was present as iron oxide and that the corresponding SiO_2 was used to make orthoclase?

could compare some flows which we knew were poured forth under a considerable depth of water, with those which we knew were subaerial. Even then we should probably find that the varying conductivity respectively of water and air was a more important factor. We have not this certainty concerning any of the flows here considered. It has occurred to me that the upper part of the series where sedimentaries are more abundant, and especially the beds around Chippewa Harbor, where the sedimentaries are fine grained sandstones, and seem to be penetrated by intrusive sills, were likely to have been deeper submarine eruptions. It would seem likely that in such a case a flow would be especially liable to be split while hot by a later flow, but that question must await farther investigation.

§ 12. Distinction between intrusive and effusive rocks.

The most important bearing of this discussion from a theoretical point of view is on the question as to the recognition of the abyssal or plutonic rocks as a separate group. It has often been denied that we can make any distinction between the more massive basic effusives and the deep seated intrusive, that is, plutonic or abyssal forms of the same chemical composition, while the marked difference between the equivalent more siliceous forms, the granites and rhyolites, is undeniable and generally accepted. But now in view of what we have seen, the question opens whether we may not seek characteristic differences, not merely in the appearance of diallage or augite, which is rather a phenomenon connected with metamorphism and of dynamic origin, but also in the character of the variation in grain. A rock may be looked on with equal justification as a geological unit, or as a mineralogical combination of certain minerals in a certain manner of texture, and according as we look at it our classification will differ, both classifications being equally justified, both having their place. But if we are to consider a rock as a geological unit, as a constituent of the earth's crust, then I presume no one will doubt that we must consider one single sheet of lava or igneous magma as one unit, and then we come to this characteristic difference between the effusives (in general) and the intrusives (in general),—that the former increase in size of grain from the margin clear to the middle, and the others have a more or less broad contact zone of uniform grain, while the deeper seated intrusives, either because of the higher initial temperature of the molten rock itself or because of the higher temperature of the rock into which it was injected, would have no marginal zone of finer grain. Of course, here, as everywhere in nature, we have transitions. It is easy to conceive that flows near their source may be superheated when coming to rest, and to imagine intrusive sheets whose conditions of cooling will approximate to those of effusion. The real determining factors of a rock are not its geological surroundings, but the physical conditions consequent upon those surroundings. These physical conditions will, however, as a matter of fact be closely linked with certain geological surroundings, and whichever we use for our classification, the important thing is that we should be able to read from the present state of a rock the physical conditions of its formation, and hence the probable geological conditions that surrounded it at that time.

The practical question for Isle Royale is whether dikes (or intrusive sheets) do play the important role that they are imagined to by N. H. Winchell (Am. Geologist, 1895, p. 270). There is no doubt that at certain points on the north side of the island the Minong trap does resemble a dike, and in a reconnoissance such as Winchell made might readily be taken for such, and I do not wish to be understood as criticizing Prof. Winchell farther than to say that in a cursory glance at a region out of his particular realm of study he seems to have been mistaken. There are other arguments enough for the non-intrusive character of the Minong trap, but the argument on which we are now dwelling is one that applies equally to practically all the other basic sheets. Their grain increases clear up to the center. Now if we compare Lawson's studies of the intrusive sills and dikes of the opposite or "North Shore," which in all probability represent deeper seated forms of the same general magma, at any rate are very similar chemically (Bull. Minn. Geol. Survey, VIII, pp. 32, 36; Am. Geol., VII, 1891, p. 153 *et seq.*), we find it distinctly stated that there is a ***rapid variation in grain for the first few feet from the contact, and then a central coarser belt of tolerably uniform grain.*** In the Stop Island dike, for example, he has given the measurements and also distinctly stated that while the dike is 150 feet wide, the grain increases rapidly for the first four feet, then slowly to 15 feet, then there is hardly any perceptible change to the center. The pyroxene, according to his figures, actually diminishes in size (owing perhaps to the chemical differentiation which is the principal subject of his paper). It is easy to see that his statement and figures point to a curve of grain like those of Fig. 17, which are from similar dikes in the South Shore Huronian. It is then evident that the conditions of grain alone would suffice to indicate that the basic rocks of Isle Royale are superficial, and I venture to prophesy that it will prove widely true that *superficial basic rocks are characterized by an increase of grain to near the center, while deep seated basic rocks have a broad central zone of nearly uniform grain.*

It may also be noticed in this connection that Lawson finds the intrusive quartz porphyrites accompanying the basic sills to be granophyric, a form of structure closely akin to the ophitic, but which we have found on the island only in pebbles in conglomerates. It is not impossible that we have here the indication of a corresponding scale of textures for the acid rocks which we have failed to find on Isle Royale, where acid rocks are the exception (Cf. Ros. M. u. Pet. Mitth., XII, 1891, p. 379).

The bearing of the above remarks upon the controverted question of the effect and importance of the geological environment ("Ort") upon rocks is too obvious to need explanation. The only thing to be noticed is that it introduces a factor hitherto disregarded, the temperature at the end of motion, as an important one. It must also be remembered that the possession and loss of gas by diffusion follow the same laws as the possession and loss of the imponderable "caloric," while the possession of gas may greatly lower the temperature of solidification as glass.

CHAPTER VI.

PETROGRAPHY.

§ 1. Work of previous investigators.

Elsewhere and especially in the preceding chapter on the grain of rocks, I have given many facts of interest which are based on microscopic studies, but which in themselves required no knowledge of the technique of microscopic work for their understanding, and were of a broader interest in the results to which they led. In the present chapter I have gathered together those facts of interest which appeal solely to the professional student, and can neither be observed nor appreciated except by one who has had some acquaintance with the use of the petrographic microscope in the examination of rocks. The Keweenawan rocks have already been ably described in reports of the Survey and elsewhere by Pumpelly, Rominger, Wadsworth, Irving and others, and illustrated by Irving with a perfection that I cannot hope to surpass. It will not therefore be necessary for me to recapitulate my observations on over a thousand slides, but rather to summarize the more important observations. If, in the course of this resumé, I am led to lay undue emphasis on the points as to which I differ from my predecessors, it must be remembered that such is the inevitable result of coming afterward. It is useless to repeat again and again in extenso what has already been well said. But since their work was done methods and instruments have been greatly improved, and if in some respects a new and perhaps ampler material, and the application of the later methods enable me to correct or supplement their results, it is but natural that a prominence to such corrections should be given, which perhaps unduly exaggerates the importance of the observations, considered by themselves.

The chief works to which I shall have occasion to refer are:

Irving: Copper-Bearing Rocks of Lake Superior, Mon. V., U. S. G. S., 1883.

Wadsworth: Bull. Minn. Geol. Survey, II, 1887. Notes on the Iron and Copper Series of Lake Superior, Bull. Museum of Comparative Zoölogy, VII, 1880.

Pumpelly: Geol. Sur. Mich., I, Pt. II. Wis. Geol. Survey, III, Pt. II, pp. 27-49. Proc. Am. Acad., XIII, 1878, pp. 253-309.

Rominger: Geol. Sur. Mich., V, Pt. I.

Lawson: Bull. U. Cal., Geol. Dep., I, p. 30.

Rosenbusch: Mikroskopische Physiographie I, 1883, II, (2nd Ed.), 1887, (3rd Ed.), 1896, Stuttgart.

Grant, U. Sherman, 22d Annual Report Minn. Geol. Survey, 1894, Pt. IV.

I shall first give a resumé of the observations by minerals, then by textures, and then by rocks. Although this may involve some repetition, it will better bring out the various relations of the observations.

§ 2. Microscopic observations on minerals.

I refer to a table of the rock-forming minerals, published in the Am. Geologist (June, 1891) and thus save repetition of the various characters by which these minerals are commonly recognized, as unless otherwise mentioned they have the characters indicated in the table.

I have used with good effect Becke's method for determining refraction, especially in distinguishing between talc and sericite, *q. v.* As it does not appear to be yet much in use among American petrographers, I may be pardoned for giving a brief account of it, especially as the original paper is not easily accessible (Sitzungs-berichte der Kaiserlichen Akademie der Wissenschaften, Mathematische-Naturwissenschaftliche Classe, Band CII, Hefte vi u. vii, 1893, Juni u. Juli, Abth. 1, "Bestimmbarkeit der Gesteinsgemengtheile", Vienna, p. 360). "With a mean focus" (on a boundary between two minerals of different refraction, which is practically perpendicular to the line of vision) "both sections appear equally bright and the bounding plane appears as a hair line. If the tube of the microscope is raised, a bright line is developed near the border on the side of the more refractive mineral, which moves away from the border, becomes broader and vaguer as the tube is farther raised. If the tube is lowered the same appearance is developed on the less refractive side." Page 361. "If the two substances interlock, by focussing too high one appears to see the whole surface of the more refractive substance brighter."

"We must narrow the cone of illumination to the angle of total reflection, to get the best results" (that is, lower the condensor, but use above an objective of wide angle). Pages 361-2. "The phenomena are the more marked, the thinner the rock section. A considerable deviation of the boundary from being exactly in the line of vision is less disturbing to the phenomenon, if the less refractive mineral is on top." Page 363. "The differences of refraction can be made still more sensible if observations in oblique light are used," i. e., cut off half the cone of rays with your hand or a card, below the rock section; "more light will go into the objective from the side of the more refractive section that is turned away from (i. e. apparently toward) the light." Cf. also Exner, Archiv für Mikroscopische Anatomie, 28, 1895, p. 97.

In applying this method we must remember that we must study one index of refraction at a time, in birefractive minerals, and that is the index of refraction for light vibrating in the plane of polarization of the lower nicol. In one position talc will appear nearly as refractive as the surrounding serpentine, in another it will appear much less refractive.

We take up the minerals in order, by groups, beginning with the primary and more basic.

Olivine. The olivine is very rarely unaltered (Ss. 15807, 15827). It is generally evidently the oldest of the constituents, rarely showing a division into two generations (Ss. 15821, 15170). There seems to have been a tendency for floating grains of olivine to cluster together (Ss. 15461, 15404, 15391), which makes it hard to give the size of the individual grains, when all are altered. Generally speaking, they are larger in the less augitic rocks (the Ashbed diabases, etc.), though less numerous. (Cf. beds below No. X, 426 ft., down to the Greenstone.)

In the ophites, as described, the olivine is crowded between the patches in minute corroded grains. In the porphyrites the glomero-porphyritic olivine-plagioclase aggregate is significant of the tendency of the magma at an early stage to crystallize out in that form, rather than as augite.

The alteration to serpentine is usually well developed (Ss. 15649, 15837, yellow-green; 15636, 15096, 15089, 15179, oily). The reddish alterations, or sometimes red with green centers (S. 15783), are also well exhibited. Figure 23, from specimen No. 15492, exhibits the exact character of the resultant pleochroism, concerning which the authorities either differ or are ambiguous.*

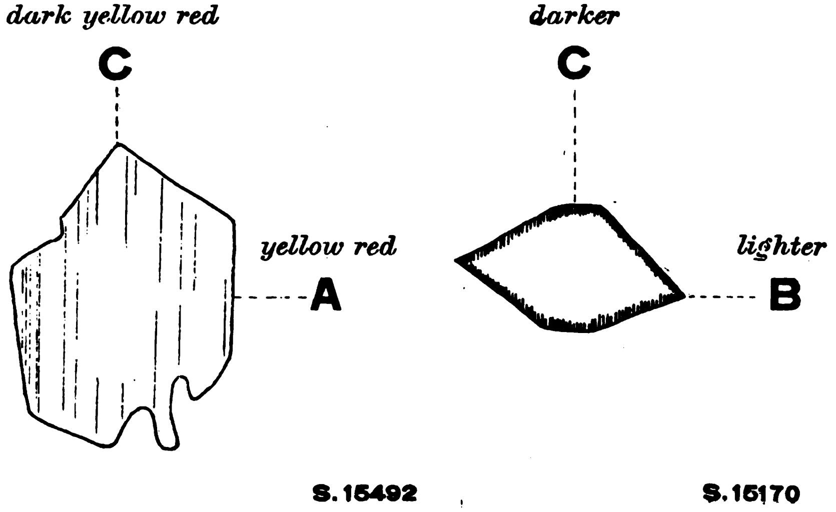

Fig. 23

Illustrates the pleochroism and optical characters of altered olivine phenocrysts.

This reddish alteration product agrees optically with Lawson's iddingsite, and I think that Lawson is right in considering the iron as largely a pigment of minute scales of hematite arranged parallel to a cleavage which is developed at the same time as the pleochroism (S 15450). The nature of the alteration product seems to vary. Sometimes it appears to be distinctly a mica, either red (S. 15083, Cf. Rominger, *loc. cit.*, p. 114), or green (Ss. 15731 15736, 15825). Again at times there is an alteration to talc, as reported by Julien (Ss. 15774, 15571), and again nothing but hematite seems to be left (Ss. 15243, 15083, 15090?). Iron oxide, especially magnetite, also occurs in the process of serpentinization (S. 15089). All the above changes are quite natural for olivine, and there is good evidence that they all occur. "Iddingsite" seems to me but a half way house. I am inclined to believe that alterations to mica are especially frequent, compared with the frequency with which they are recognized.

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* Geol. Sur., Mich. 1895, Rominger, V, Pt. I, pp. 114, 124; Rosenbusch, Mik. Phys., II, 1887, pp. 489, 512, 1896, p. 963; Lawson, Bull. U. Cal., Geol. Dep., I, p. 30, "Iddingsite." Irving, *loc. cit.*, p. 39. See also Fig. 29.

In regard to the alteration to magnetite, while it is hard to distinguish the magnetite from the hematite when they occur together, magnetite does often occur but generally under such conditions, replacing the olivine in such a way, not strictly pseudomorphic, (S. 15493) *and yet taking its place* as an element in the texture, that it seems to be a primary or magmatic replacement, due to oxidation in the still fluid magma.

The reason why Irving reports no olivine from the Ashbed diabase group, and includes as olivine-free diabases many rocks which I should class as melaphyres, *e. g.*, Marvine's bed No. 87, is probably that his sections showed no fresh olivine, which as we have seen is not surprising, and he interpreted the pseudomorphs as augite. But the analysis, *loc. cit.*, p. 66, which is like ours of specimens Nos. 11515-15523, shows plainly enough with 5% of alkalies and 13% of FeO and MgO, and not enough SiO_2 for the anorthite ratio, that if the original rock has not been entirely altered in composition it must have contained olivine, as both oligoclase and augite would imply much higher percentages of SiO_2. And in fact I did not doubt before having any analysis made, nor do I think anyone of experience would doubt, that the pseudomorphs were after olivine.

Augite. When the augite is scarce, it is idiomorphic and colorless (Ss. 15531, 15328, etc.). When a little more abundant, it may appear in sheaflike or shredded forms (Ss. 15622, 15537, 15926). Around an amygdule it often has arborescent forms (S. 15618). When moderately abundant (Irving's "ordinary type diabase"), it is in granules (Ss. 15494, 15783) or in xenomorphic wedge shaped forms (Ss. 15393, 15841), dependent somewhat upon the nature of the accompanying plagioclase. It has evidently more tendency to be idiomorphic against the plagioclase, the less lime the latter has. Sometimes it seems just on the border line, patchy, and in part idiomorphic (S. 15349). Commonly, of course, it is poikilitic, enclosing the feldspar laths. To this variety of poikilism the term ophitic is applied. But even when the augite is thus ophitic, it is not, as is sometimes said, necessarily without form of its own. For example, in S. 15834 the poikilitic augite is in long prisms. A significant variation from the ordinary rules is in S. 15428, where the augite is extra coarse along a vein with amygdaloidal filling. In the doleritic type of structure it may be long and idiomorphic (octagonal prisms); so is the feldspar also (S. 15275). It occurs occasionally, but not so characteristically as the feldspar, in nests (Ss. 15148, 15784) and also in two sizes (S. 15784), the larger size however not apparently indicating any great break in the process of crystallization.

When the augite is more abundant the brownish tint is more marked, but I have not noticed the strongly pleochroic variety with violet hues that sometimes occurs.

The decomposition of the augite to chlorite, *q. v.*, is everywhere to be seen. Epidote prisms as an alteration product of augite are not infrequent (S. 15516). In contrast to the frequent mention of uralite after augite or primary hornblende, from other parts of the Keweenawan, I may say that I have found hornblende in any shape extremely rare. (S. 15534?).

Rounded granules of augite, quite fresh too, are often found in the basic sediments (S. 15043).

Feldspars. This group is well represented in its range from orthoclase (Or. = K_2O, Al_2O_3, $6SiO_2$) to albite (Ab. = Na_2O, Al_2O_3, $6SiO_2$) and nearly to anorthite (An. = $2CaO$, $2Al_2O_3$, $4SiO_2$) (S. 15666). The group of the soda-lime feldspars is of especial importance, and Plate V shows the chemical composition corresponding to various proportions of the constituent molecules. It also shows the method I have very generally used in the determination of the feldspars. As has been long known, the extinction angles of the feldspars depend very closely on the percentage of lime present. Pumpelly, even at the early date of his work, appreciated their importance and made good use of them, and Irving followed his methods (*loc. cit.* p. 39). While in general Pumpelly had caught the right idea, his method was deficient in that the distinction between positive and negative directions of extinction, *i. e.*, between those of greater and less refraction, was not noted, and the limit of extinction angles for anorthite was put too low. The farther development of the theory of the feldspar series by A. Michel Lévy, Schuster, Mallard, and others, is in all the petrographical text-books; I have used the statistical and other methods, and the diagrams already printed. The method which I have thought it worth while to illustrate by plate V, is one suggested by Lévy in his "Détermination des feldspaths", which is the best book yet published on the subject. This work enables one to determine the lime percentage in a single compound individual, and there is scarce a thin section but will furnish many such.

If we have four sets of feldspar lamellæ occurring as two compound individuals composed of albite lamellæ, which individuals stand in the relation of Karlsbad twins to each other, then when they are cut perpendicular to the lateral pinacoid (M) we shall have two sets of extinctions symmetrically arranged on each side of the dividing lines parallel to M. If these dividing lines are turned until they are at 45° to the plane of the nicols, the individual will appear to consist of but two parts, but there will be no position in which the whole compound individual will appear to be equally illuminated. Now it is possible to determine from Lévy's data, what the one set of extinctions will be if the other set are given, for the various species of feldspar produced by the various intermixtures of the albite and anorthite molecules. Hence we have plotted curves for the various feldspars, showing this connection, the value of the less extinction being taken as abscissa, and of the greater as ordinate. The results may be checked by the statistical method, or Michel Lévy gives a formula for the relative birefraction which may also be used as a check. Generally speaking, the set with the greater extinction angles have the less birefraction (Ss. 15499, 15523). We may also check up our observations of extinction by reading on the positions of equal illumination which are connected with the birefraction.

For example, take the Greenstone. In S. 15252 we have the following observations

Alb.	K.	*Alb.*
19°-19°	with	41°-
30°-28°	with	37°-
34°-24°	with	38°-
31°-23°	with	23°-
39°-34°	with	6°-2°
S. 15254		
25°-27°	with	9°-4°

which indicate very plainly a curve for all the observations which are nearly symmetrical, between Ab_3 An_4 and An, really about Ab_1 An_2 and near the common formula for labradorite, Ab_2An_3. One big porphyritic crystal gives the higher values of 43°-43°.

In this way the statements scattered through this report were substantiated concerning the feldspars. Of course a good many readings were made on simple albite twins besides.

Orthoclase occurs rather rarely in a form that may be certainly identified. It occurs in large corroded phenocrysts in quartz porphyries and orthophyres, which are represented mainly in the conglomerates and tuffs (S. 15951). In S. 15955 it has a curious porous structure.

Triclinic and twinned crystals with very low extinction angles occur in connection with the orthoclase under the same circumstances, and occasionally appear to be anorthoclase (S. 15436), but I have not made sure that they are. They too are corroded very often (Ss. 15237, 15897). Besides occurring in the conglomerates they occur in the Huginnin porphyrite (drill hole No. XIV, S. 15816, etc.) and similar corrosion occurs in the Minong porphyrite (drill hole No. 1, Ss. 15046, 15052, Pl. VI, fig. 6, etc.). In these cases they are in size very distinct from the mass of the feldspars, and may be true intratelluric products, showing some signs of corrosion. Were it not for the character of its feldspar, the Huginnin porphyrite would be a type of labradorite porphyrite.

In the main occurrence of the oligoclase feldspar, it has a somewhat different character. Sometimes very clearly porphyritic, or at least subject to the accidents of motion, the feldspar as a whole is not divisible into sharply separate groups, but we have every gradation of size down to the smallest, showing that although the feldspar began to form before the flow came to rest, its formation continued thereafter. In such case we are very likely to have a glomero-porphyritic texture (Pl. VI, fig. 4), that is several of the larger feldspars are likely to be grown together in aggregates which it seems a stretch to ascribe even to the ineffable complexity of feldspar twins, though we can in favorable cases recognize the presence of the Manebach (S. 15578), the Baveno (Ss. 15537, 15801) and probably other laws. Even if the feldspars are now in twin position, the evidence at times is clear that they were formed separately, and clotted together. Zonally varying extinctions, indicating variation of chemical composition, are not uncommon (Ss. 15767, 15828), and sections parallel to the lateral pinacoid (010) M are especially instructive (Ss. 15361, 15784). Not always are the margins more albitic (Ss. 15328, 15329), but this is generally true.

In a number of flows which stand as connecting links between the Ashbed diabases or navites (below, § 3) and the ophites the feldspar often differs in character from the top to the bottom of the flow. The flow in drill hole No. X (Ss. 15514-15524), from which the analyses were made, is one such,—S. 15515 giving 4°-9°, with 3° extinction angles, etc.; S.

15517 giving 21°-16° with 3°, and 6°-5° with 16°, etc.; S. 15521 giving 6°-6° with 23°-23°; S. 15522 giving 11°-18° with 29°-34° and 33°-34° with 10° extinction; S. 15523 giving 24°-20° with 42°-39°, 24°-23° and 19°-18° with 37°-33°; 24°-20° with -32°, 28° with 40°-37°; and S. 15524 giving 14°-11° with 26°-38°, 20°-17° with 35°-43°, and 13°-20° with 36°-37°. These plotted on Plate V show a well marked variation from andesite down about to the feldspar of the Greenstone, the normal labradorite type. Other similar cases are the bed at the bottom of drill hole No. IX (Ss. 15454-15461). drill hole No. VIII (Ss. 15354-15364) and below, and drill hole No. IV (Ss. 15176-15183).

In the well marked ophites the feldspar is generally a normal labradorite and the extinctions rarely indicate a less proportion of An to Ab than 1 : 1. Occasionally a feldspar close to anorthite is indicated (S. 15609, 21°-30° with 45°-45°), as is the case toward the middle and bottom of the big flow at the top of drill hole No. XIV. Baveno twins are very common. When the crystals are flat tablets, owing to the development of (010) M, Baveno twins give cruciform sections which are common and characteristic. Some of the finer grained basic sediments are largely composed of labradorite sand (S. 15161).

Coming to the smaller feldspars, we find rarely indications of three periods of feldspar growth (S. 15441). Very commonly and uniformly at the margins of the flows there are indications of two periods, the younger feldspars being mere trichites, with a very strong tendency to protruding angles and edges, which give characteristic forked and hollow forms (S. 15572) and skeletal outlines (Pl. VI, figs. 1 and 5, Ss. 15300, 15368, 15334). These trichitic additions naturally use the porphyritic crystals for foundations (Plate VI, fig. 1, Ss. 15092, 15186). But the very flows so markedly porphyritic at the margin may show little or no trace of it at the center, showing that far from the margin the coming to rest produces no sudden change in the conditions of cooling and solidification. There are evidently two marked epochs of alteration in conditions of solidification in the history of the feldspars; one is when the change from internal to superficial conditions takes place,—the eruption,—the second when the cessation of motion takes place, or, as we may say, the beginning and end of eruption. It is often possible to distinguish the products of the three periods separated by these two epochs. Much of the feldspar appears to have been formed between them.

Glomero-porphyritic feldspar aggregates also occur in the various tuffs and conglomerates, in many cases like those of associated flows (S. 15431). Feldspar is also alluded to by Koch as a secondary mineral. I have not noticed it.

Quartz and the other forms of silica (SiO_2).

The most distinct primary forms of quartz are the phenocrysts in quartz porphyries, which have been so admirably illustrated by Irving, that little remains to add. I have met them at Isle Royale only in conglomerate pebbles (Ss. 15237, 15890, 15902, 15922, 15949, 15950) unless in S. 15998 there is a small exception. They are generally corroded.

Quartz occurs abundantly in poikilitic secondary patches, sometimes so replacing a fine grained porphyrite, that while in ordinary light the microlitic flow texture is perfectly plain, in polarized light it is entirely disguised. In all respects it corresponds to the micropoikilitic patches described by Miss Bascom (Journal of Geology, I, 1893, No. 8, p. 816), and is referred to by Irving (*loc. cit.*, pp. 113 and 114) and by Wadsworth as well. It is not quite clear however, from Irving's descriptions, whether he did not lump the micropoikilitic and micropegmatitic textures together, as secondary quartz (*l. c.*, p. 100), though he alludes (on page 113) to the characteristic difference, viz., that in the micropegmatite the feldspar with which the quartz is intergrown has continuous orientation as well as the quartz, while in the secondary poikilite, quartz embeds and surrounds or replaces whatever comes in its way with no regard to previous orientation. If we do make this sharp distinction, as we ought, between poikilitic quartz and pegmatitic quartz, then I must say that a large part of the quartz that Irving and Wadsworth consider secondary, namely that which is pegmatitic, I do not so consider. It seems to be the normal mode of solidification of the acid magma under certain circumstances. In other cases it is the mode in which the more basic rocks have, under conditions of intrusion, filled the last interstices, which would otherwise be miarolitic. (See my discussion of quartz diabases in Chapter X.)

In this connection it may be as well to speak of spherulites, though they may not be really quartz. Irving did not happen to see any. On Isle Royale they occur in the Minong porphyrite at McCargoe cove (S. 16082) and in the porphyry tuffs (Ss. 15902, 15922, 15949, 15950).

Quartz also occurs abundantly in amygdules with epidote, etc., (S. 15820) as has been already so carefully described in our reports by Pumpelly. In S. 15114 A, from above the Minong trap, there is a section of an agate, such as are characteristic of this bed.

This bed is quite chalcedonic (S. 15120) in parts. Chalcedony and chalcedonic quartz also occur commonly in the tuffs, very markedly in the last one toward the bottom of drill hole No. XVI, immediately above the porphyry. Chalcedonic dots, and white margins to the ash fragments are characteristic of this whole formation (Ss. 15986, 15982, Pl. VI, fig. 2, etc.). Chalcedony also appears to occur coating miarolitic cavities (S. 15499).

Amethyst occurs around the outlet of Siskowit Lake.

Iron ores and ferrites. The somewhat old fashioned term "ferrites" is not objectionable if one distinctly understands that ferrite does not mean any one mineral, but is a group name for translucent, red to yellow, hydrates or oxides of iron.

Magnetite occurs at times in coarse distinguishably .octahedral grains (Ss. 15126, 15831–3, 15906–17, etc.), and more often in finer grains It most often occurs, however, with the serpentine or other pseudomorph of olivine in such relation that we may say they make a grain together, and it seems to have formed from the oxidation of the iron olivine. In the ophites, for example, it mostly occurs thus crowded with the olivine into the interstices of the olivine patches. As a fine dust it is universally distributed (S. 15174), more abundantly in the more basic rocks. Not evenly, however, for sometimes it gathers into spots around which there is a clearer halo (S. 15566), or gathers simply into blacker spots (S. 15123) and club shaped and branching aggregates (S. 15640, as illustrated by Rosenbusch, I, Pl. III, fig. 2), or, especially in the less augitic types, around their small pores makes a darker border (Plate VI, fig. 4, and S. 15117, the Minong porphyrite; Ss. 15811, 15950, 15951). In many such cases its primary nature is by no means certain. Where, as in S. 15960, it outlines a perlitic texture or structure, it is more certainly secondary.

Of the other iron oxides,—

Hematite occurs more rarely (S. 15008) in irregular skeletons (S. 15520) Cf. also S. 15380.

It occurs sometimes in the coarse doleritic spots in the form of flat plates (Ss. 15912, 15544), and elsewhere quite frequently, and also in red ferritic form, in connection with alteration, and in the more feldspathic rocks, in certain kinds of alteration. *Ilmenite* also occurs (S. 15455) and also *leucoxene* (S. 15534), its alteration product. Whether the triangular outlines in S. 15520 indicate an original intergrowth of ilmenite and magnetite is not quite certain.

Ferritic discoloration, as described by previous authors, is widespread, giving to the sedimentary beds and to the red amygdaloids their characteristic red color; the amygdaloids at the bottom of a flow are more characteristically red in color than those at the top. The decomposition of the melaphyres seems sometimes to be accompanied by oxidation, and then ferrite is abundant. At other times the change is more of a pure hydration, and then ferrite may be wholly absent, being replaced by a magnetite dust, while chlorite and serpentine are abundant. In such secondary viridite, opaque trichites of decomposition occur (S. 15577).

Viridite. This somewhat old fashioned name (Vogelsang) is, nevertheless, a very convenient one for the secondary hydrous magnesian silicates of a green color described below, which probably form an isomorphic series like the feldspars. Their optical properties are certainly variable. I have discussed the optical properties of the group quite fully elsewhere, in connection with the quartz diabases. The process of alteration has been quite fully described by Pumpelly, and I have few facts to add, though some differences in interpretation to suggest.

Serpentine occurs as usual, and after olivine, *q. v.* At times it appears to approach bastite in its form, but I have never been able to convince myself that any enstatite was originally present (S. 15510).

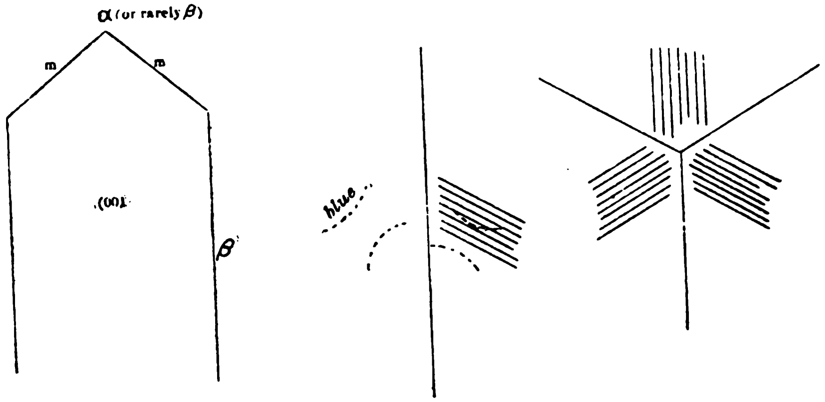
Chlorite. There are two kinds of chlorite, which we may call delessite and chlorite, the former being the more birefractive and the more pronouncedly fibrous (S. 15332). They occur;—

(1) Lining amygdules,—generally delessite—

(2) Coating cavities of irregular shape but bounded by the idiomorphic crystals of the groundmass (Plate VI, fig. 3). These are taken by Pumpelly to be replacements either of augite or of some mesostasis (Irving, *l. c.*, p 65), though the idea that they might in some cases be the replacement of a pre-existing cavity, evidently occurred to him. When we study some of these cavities carefully, I think we shall be convinced that associated as they are with the general doleritic texture, and marked by a continuous band of delessite around their walls with its fibres perpendicular to the walls which band may be replaced by quartz or chalcedony, other filling material being various, they are the interstices which would necessarily be left in the process of cooling and complete

crystallization, and are akin to the miarolitic texture, and correspond to the micropegmatite interstices of the quartz diabases.

(3) Chlorite often occurs after augite also, of course; also as amygdaloidal filling, and, as Pumpelly describes, secondary after prehnite. "Chlorastrolite" seems to be a name applied to certain amygdules which have resisted weathering better than the matrix; in these amygdules the chatoyant effect produced by a fibrous chlorite rind is retained.



S. 15508

S. 15382

Fig. 24.

Illustrates the form, optical orientation, and some of the twinning phenomena of prehnite.

Prehnite. We class this with zeolites, from its association and behavior. It is the most abundant and characteristic replacement mineral, occurring in veins (S. 15521), in amygdules (S. 15508), and replacing the whole mass of the rock or the feldspar (S. 15508), with copper (Ss. 15149 and 15150) and quartz (S. 15820), with quartz and epidote (S. 15644), and with other zeolites (S. 15373). The order of occurrence has been carefully studied by Pumpelly. It differs in its characters from those indicated by its position in the table referred to, only in that +2V is likely to be small, and the dispersion is likely to vary even in the same slide. This is due to the oft described twinning (Neues Jahrbuch für Mineralogie, 1888, I, p. 91) which can often be recognized. In S. 15508 the prism m (110) and pinacoid b (010) can be recognized; Fig. 24 shows its optical orientation. The extinction of the principal zone, i. e., extension, is almost invariably negative, not always however. The pink prehnite does not appear as such in thin section (S. 15651), but S. 15149, which shows copper crystals under the microscope, shows a light flesh pink color to the naked eye.

Laumonite is well characterized, as indicated by its position in the table (Ss. 15453, 15352, 15087). At least two cleavages are distinct; a diagonal twinning (100) corresponds to that described, and bisects (110) the cleavage. A small —2V and large extinction are normal. Cleavage fragments, however, which have been for some time in the collection, show abnormally small extinction angles, which may be attributable to loss of water, or possibly to conversion to leonhardite. Other sections interesting for zeolites are Nos. 15373, 15303, and 15275.

Thompsonite is a very common zeolite on the island, but I have not happened to meet it in any of the sections examined by me (S. 15826?).

Analcite, which occurs frequently in the more feldspathic melaphyres, in distinct crystals in the incompletely filled amygdaloidal cavities, has also not been recognized under the microscope, but owing to its isotropic character and weak refraction it might easily be overlooked. A special test of the solubility and gelatinization of S. 15515, whose analysis indicated that it might have been present, was made with a negative result. As I remember, it occurs (Sp. 15289) more in the Ashbed diabase group, above the Greenstone, i. e., in the rocks that contain more soda, where it might be expected.

Apophyllite is mentioned by Koch, p. 188.

Whether the reddish yellow feldspathic mineral mentioned by him is really feldspar, as it may be, or possibly some undescribed zeolite, I dare not say.

Pectolite is also reported by Foster and Whitney (*loc. cit.*, p. 105).

Wollastonite has been described by Foster and Whitney (*loc. cit.*, p. 108) from Scovill Point.

Calcite is of course abundant, in amygdules, in replacement, and in veins. Section 15743 shows an interesting case of calcite between layers of peeled off clay, and it occurs very abundantly as a cement in the conglomerates (Ss. 15043, 15778). It is very commonly poikilitic (S. 15705), large secondary patches extinguishing all together. This produces a lustre mottling, which must not of course be confused with that of the augite. In general the calcite presents no features unusual in the Keweenawan rocks.

Aragonite. In one section, No. 15820, a mineral appears with —ex. 0°, strong birefraction, something like that of white mica, with moderate refraction in the direction of elongation, in the other a stronger refraction, stronger than that of chlorite in which it occurs, which could not be certainly determined, but agrees with aragonite.

Chlorastrolite (Jackson, 418; F. and W., II, 97; Hawes, Am. J. Sci. X, 1875, p. 24; Foote Am. Ass. Adv. Sci., 1872, p. 65).

The chlorastrolite question will probably be taken up later in a report devoted to mineralogy. Here I will only say that I agree with the view that it is not a mineral by itself, and hence it is no wonder that it has not been recognized as such by me in thin section.

Epidote. This mineral is abundant and well characterized. The ferriferous yellow and not the zoisitic varieties are best developed. It occurs in veins (S. 15:81), in the fragments of conglomerates (S. 15633), in amygdules (Ss. 15435, 15820), and is most often associated with quartz (Ss. 15820, 15435). It is often in sharply defined crystals.

Datolite, so far as noticed, is of the porcelain variety, of almost submicroscopic fine grain.

Copper seems to occur in minute cubes or octahedra, when it occurs in microscopic size. It occurs, when noticed in thin section, enclosed in prehnite (Ss. 15150, 15149). All the depths at which copper occurred are noted in the geological column.

Mica. The micaceous minerals replacing olivine have been already noted (also S. 15355). A sericitic mineral often occurs after feldspar.

Clay. The clay of the flucans (S. 15680) has almost no action on polarized light.

Apatite occurs as needles imbedded in quartz in the interstices of the dolerite (Ss. 15615, 15126), also occasionally in pebbles from the more acid rocks (S. 15586). The occurrence of apatite in the interstices parallels that in the quartz diabases.

Fluorite occurs in the porphyry tuff immediately above the porphyry at the bottom of the cross-section (Ss. 15972, 15976). The blue pigment is irregularly distributed and the cleavage is well marked. The color is really blue, rather than violet.

Amphibole is as rare in these rocks as it is prevalent in the Huronian rocks. However, in S. 15534, secondary actinolite needles appear to be present in a much altered porphyrite.

§ 3. Textures.

Among the textures worthy of mention are:

(a) Igneous central; *ophitic,* that is, with poikilitic augite enclosing idiomorphic feldspar with the lateral pinacoid and the direction of ă best developed. This is a variety of the general poikilitic texture, and is well illustrated in Rosenbusch (*loc. cit.,* II, Pl. II, fig. 3) and in Irving (*loc. cit.,* Pl. IX), and its weather surface by Pl. VII of this report. Olivine is crowded in corroded fragments in between the patches, and is associated with abundant magnetite.

(b) Igneous central; *doleritic* (Pl. VI, fig. 3). In this the feldspar and augite are more nearly of a size (S. 15493) and between them are interstices, which may of course at times be filled with glass or decomposition products of glass, but in typical cases the surrounding augite and feldspar are idiomorphic against these interstices, which are lined with a border of chlorite or chalcedony, and then filled in with chlorite, quartz, etc., and may be crossed with apatite needles (Ss. 15499, 15615, 15674. Cf. the apatite of Capo di Bove). In transition forms this may be combined with the ophitic texture (Ss 15090, 15201) or with decomposed glass, etc , to produce the tholeyitic* texture or intersertal structure. (Rosenbusch, *loc. cit.,* 1896, II, 1072, and his Pl. IV, fig. 2.) Some of Irving's orthoclase gabbros seem to have a parallel texture.

(c) Igneous central: *navite* type (Pl. VI, fig. 4). The groundmass, so far as can be seen, is composed of idiomorphic feldspar laths of the oligoclase series, and a small amount of idiomorphic light colored augite. The feldspar occurs largely porphyritic, but not sharply separated from the groundmass. As a matter of fact, though not affecting the texture, in which they play no role, porphyritic olivines are large and few. Irving's Fig. 3 and Fig. 4, Pl. X, belong to this type, though neither is very characteristic. The one is decomposed, and the other does not show as much variation in the size of the feldspar as is common. The larger feldspars tend very strongly to gather together,—become "glomeroporphyritic" (S. 15438), while at the same time they do not lose their connection with the smaller feldspars. Rosenbusch's Pl. IV, fig. 2, might be taken to be a magnified view of a not very porphyritic part, while Fig. 3 would also be representative. This type can pass by increase of augite, toward the bottom of the flow, into the ophitic type,

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* The town of Tholey is commonly thus spelt in atlases, and it is much more in accord with the usage of the English language to spell tholeyitic rather than tholeiitic and slavishly follow the Germans who do not use y.

(S. 15513–15524); by growing finer and glassier, and more markedly porphyritic toward the margin, into the "microlitic" type (Lévy) or hyalopilitic type (Pl. VI, Fig. 5). These transitions may take place in the same flow. In comparing different flows we find generally, with decreasing augite or olivine, that the distinction between the younger and older crystals becomes sharper and sharper, as in the Huginnin porphyrite (Ss. 15811–15818) and in the Minong beds. Thus we have the pilotaxitic variety of the microlitic texture, somewhat like Irving's Fig. 2, Pl. X, which is however more hyalopilitic, according to description (Rosenbusch, *loc. cit.*, 1896, Pl. IV, fig. 1, Pl. V, fig. 2).

Coming now to the marginal textures, we have

(d) The *amygdaloidal* (Pl. VI, fig. 5), full of gas bubbles, more or less filled.

These bubbles are larger in the more augitic rocks, smaller and finer in the more feldspathic ones. Around the amygdules the grain becomes finer, (Ss. 15008, 15117, 15811); the feldspar assumes forked, skeletal and trichitic forms (S. 15572; Rosenbusch, *loc. cit.*, I, Pl. II, fig. 4); the augite may be arborescent, and the iron oxides gather or become more conspicuous. The foot wall amygdaloids seem more ferruginous than the top, and less amygdaloidal. Their amygdules are often long tubular amygdules, whose lower end is at right angles to the bottom of the bed.

(e) The general texture surrounding the amygdules is *microlitic* (Pl. VI, figs. 5 and 1, and generally more or less glassy, and flow lines may be obvious.

(f) Actual examples of a thoroughly glassy texture, *vitrophyric*, are usually confined to a few millimeters from the contact. It is in the basic rocks brown or yellow brown, and soon decomposes (Ss. 15366, 15106, 15110, 14748, 15566–15572, 15508, 15644).

Among the sedimentary rocks,

(g) The peculiar concave forms of *ash* are well illustrated in Pl. VI, figs. 1 and 2 (Ss. 15417, 15260, 15962, 15982, 15277). Sometimes the fragments are charged with epidote (S. 15633), sometimes coated with chalcedony, from the large amount of soluble SiO_2 that necessarily occurs in a glass deposit (S. 15962); often they are dotted with iron oxides.

§ 4. The rocks.

We give in the appended table a revised extract from the classification of the rocks according to Rosenbusch, which I published in the American Geologist, wherein are the types of igneous rocks found on Isle Royale. Of the divisions made by Irving we may mention,—

I. *Basic original rocks,*

A. Coarser grained rocks, the orthoclase-free diabase and gabbro, and olivine gabbro, so far as represented on the island, are by us included under doleritic and ophitic melaphyres. Among the above coarser grained rocks Irving includes the coarser part of the Greenstone, but as we interpret the beds, we cannot agree with his statement, page 69, that the coarse and fine kinds are not found grading into one another in any one bed. The true deep-seated rocks, the orthoclase gabbro, the hornblende gabbro, and the anorthosite seem to be unrepresented.

B. Fine grained basic rocks.

(1) The olivine-free diabases of the ordinary type. (Irving, *loc. cit.*, p. 61.) These are, as Irving says, the smaller flows, in which the change from marginal to central texture has not advanced enough to be characteristic. The feldspar is oligoclase. They are more or less altered, but I do not think there can be much doubt that they were originally olivinitic,—at any rate, that that was the case for the type bed, Marvine's bed No. 87, which has been analyzed (see end of Chap. IX; Irving, *loc. cit.*, p. 66). I class them therefore among the melaphyre porphyrites, as we class the latter, going back to Streng's word (N. J., 1877, p. 41), i. e., melaphyres close to the spilites. (See also Zirkel, Petrography, 1894, II, p. 701; Rosenbusch, *loc. cit.*, 1896, II, pp. 1061, 1064.) Fig. 3, of our Pl. VI illustrates a coarse form of the same family.

(2) Irving's second group (p. 68), the olivine diabases and melaphyres, are precisely our ophites, and Rosenbusch's olivine tholeyites. It should be remarked perhaps, that the degree of alteration which characterizes the rocks to which the term ophite was first applied, has nothing to do with the definition, as used by A. Michel Lévy. Fouqué and Lévy called a certain group of their artificially formed rocks ophites.

(3) In his third group, diabase porphyrite and Ashbed diabase Irving, as he himself recognizes, has rocks of widely different character, with SiO_2

ranging from 48% to 60%. We may subdivide this group into the following groups:

(a) The more pronounced porphyrites of the Ashbed diabase type, where the augite is scarce and idiomorphic, the olivine not very abundant, the feldspar oligoclase and more or less porphyritic, Pl. VI, fig. 4, there are, as Irving says, gradation forms from these rocks to his "ordinary diabases," i. e., according to my grouping they both belong to the same group of melaphyre porphyrites. As they are well developed on the north side of Tobin Harbor, we might call them the Tobin porphyrites. They are Rosenbusch's navites.

(b) The Huginnin porphyrite type, in which large oligoclase phenocrysts lie in a fine grained groundmass of alkaline feldspar, in which some orthoclase may be included (Pl. VI, fig. 5, Ss. 15811-15818). Olivine is not present. This is not a melaphyre at all, but an augite porphyrite, close to the "plagiophyres", and but for the character of the feldspar would be classed with the labradorite porphyrites

(c) Finally, a still less augitic group, in which the augite is present only, as we may say, as an accessory; orthoclase is almost certainly present, though not readily recognized, and spherulites may occur. The most important representative of this group is the Minong porphyrite, which falls under the felsite porphyrites, or felsophyrites, e. g , S. 15045 *et seq.*, from drill holes No. I and No. III. All these types may be recognized also in Irving's descriptions.

The remaining more acid types are present only in pebbles, so far as we know, except at the very bottom of our cross-section, where we have a red aphanitic felsite. Under

II. *Acid original rocks,*

Irving makes four divisions:

(1) Quartzless porphyry (p. 91), including only kinds with 60% to 70% SiO_2. The porphyritic crystals are orthoclase and oligoclase, the former prevailing. This type is abundantly represented in the conglomerates (Ss. 15550, 15555).

(2) Quartz porphyries and felsites (p. 95), the latter term applied to the kinds not evidently porphyritic. This includes both Rosenbusch's orthophyres and quartz porphyries. Both types are present in conglomerates quite abundantly (Ss. 15546, 15576, 15578, and at the bottom of our column is a felsite, S. 15986). Spherulites, which Irving did not happen to encounter, occur abundantly in conglomerate pebbles (Ss.

15578, 15579, etc.) and also occur in the Minong porphyrite (Sp. 16082). Quite a common type not emphasized by Irving, among the porphyries, is that of quartz porphyrite (S. 15579). Throughout the series it seems to me that oligoclase or albitic feldspars are quite abundant, but I cannot say that any proper keratophyres occur.

(3) The granitic porphyries, augite syenite and granitell of Irving (p. 112 and Plates XIV and XV) are granophyres and granophyrites. The difficulty which Irving found in naming them arises from the fact that he considered the quartz of the micropegmatite as secondary.* The descriptions and illustrations as given by Irving are very clear and accurate, whatever may be the interpretation put upon them. In this connection Bayley's work on Pigeon Point, Am. J. S. XXXV, 1888, p. 388, also XXXVII, 1889, p. 4, and XXXIX, 1890, p. 273, and Bull. U. S. G. S., No. 109; and Harker's work on the Carrock Fell (with whom I agree in general), Q. J. G. S., 51, 1895, p. 126, and 50, 1894, p. 311; and Grant's on augite soda granite, Am. Geol. XI, 1893, p. 384, and Pt. II of the 21st Ann. Report, Minn. Geol. Survey, 1892, dated 1894, should be consulted. Waiving the question of the anorthoclastic character of the feldspars, the name augite granophyrite will be applicable to most of these rocks. This group is on Isle Royale practically absent, and rare even in the conglomerates (S. 15481).

(4) Granite (p. 125) fails entirely, even in the conglomerates, so far as I have noticed, until we come to the pebbles of the recent gravels, but I do not intend to take up the petrography of the glacial deposits, except to state that a wide variety of rocks is represented in them. Irving's

III. *Conglomerates and sandstones* may be separated into the following not sharply distinguished classes:—

(1) Ash beds, properly so called, having the constituent fragments in the conchoidal forms of glass ash. These were not noticed by Irving but they do occur (Pl. VI, figs. 1 and 2, Ss. 15260, 15417, 15418, lowest tuff in drill holes No. XII and No. XVI and Ss. 15430-15432).

(2) Scoriaceous conglomerates. Irregular masses or bombs of amygdaloid together with the rough and irregular top of the underlying sheet are cemented together with a fine grained red matrix. This includes a

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*My views on the subject will be reserved for my discussion of the micropegmatite in diabases, in Chapter X.

portion of the so called "Ashbeds" and part of the scoriaceous amygdaloid beds.

(3) Conglomerates, having rounded pebbles of various kinds.

(4) Tuffs, having fragments mainly of one, probably contemporaneous rock, mingled with some ash.

(5) Sandstones, finer grained than the conglomerates, so that the nature of the constituent fragments is not apparent to the naked eye. If they are largely derived from basic rocks, and this is often the case, they are made up of granules of plagioclase, augite and the like, and may be called basic sandstones.

(6) Shales, still finer grained, so that the material is largely not rounded, having been carried by flotation. The material is much decomposed into clayey matter.

§ 5. Petrographic review of geological column.

We will now briefly review the geological column, for petrographic notes.

(0 ft.) in cross-section.

In drill hole No. XI down to 389 ft. the trap beds are comparatively thin melaphyres, largely amygdaloidal, but at once showing the ophite type as soon as they become a little compact, the feldspar labradorite, the olivine in small granules (0.20 mm.). The associated conglomerates show quartz porphyry, orthophyre, oligoclase porphyrite, decomposed melaphyre (S. 15559) and spherulitic porphyry pebbles (S. 15591), often with a calcareous cement, and often, too, showing the secondary poikilism of quartz; also chalcedony (S. 15599). Sedimentary veins, "clasolites", occur, and glassy contacts are well represented. No. XI, 389-396 is an amygdaloidal melaphyre with low angled feldspar. It is altered and gives one of the best illustrations we have of secondary poikilitic quartz (S. 15659). Both these and the flow below, No XI, 396-457, show a tendency to two generations of feldspar and the lower (S. 15666) carries some porphyritic feldspar near anorthite.

Below this lower flow is a well marked basic sandstone, the porphyry fragments absent, but epidote, plagioclase, augite, etc., abundant.

The remainder of No. XI consists of small flows, mainly amygdaloids (spilites; feldspar from andesite, S. 15697, to anorthite, S. 15704).

The conglomerate, No. XI, 493-499, shows spherulitic poikilitic orthophyre, quartz porphyry, quartz porphyrite and ophite, pebbles.

Down to the conglomerate, No. X, 170-193, the succession of minor flows continues,—normal ophites when not amygdaloidal. The feldspar of the marginal amygdaloids gives lower extinction angles than the feldspar of the centers. Is this perhaps due to an elongate rather than to a tabular habit? The extinction angles of the center indicate labradorite near Ab_3An_4.

(567 ft) No. X, 170-193. The pebbles of this conglomerate are like
(589 ft.) those of the conglomerates above, except that S. 15486, a
glomero-porphyrite, seems to be a new type.

No. X, 193 306. This big flow is not lustre mottled, and most of the feldspar is Ab_5An_3, though in and near S. 15499, at 272 ft., it is more basic. The olivine is much larger than in the ophites above (up to 2 mm.). The distinction of this melaphyre porphyrite from the ophites is marked, but there is still a good deal of augite in it. (Pl. VI, fig. 3.)

The record is confused for the next 20 feet, but within the interval there is plainly an ophite with labradorite (S. 15507). Then beginning at 338 ft, or a little higher, and extending down to 415 ft., a flow comes, which has been analyzed (p. 145), like the melaphyre porphyrite just mentioned, but more basic at bottom and then somewhat poikilitic (S. 15522) and also doleritic (S. 15521), in the latter case with chloritic rinds around the feldspar.

(806 ft) No. X, 415. This conglomerate contains only fragments
(817 ft.) with a microlitic texture; at top it is composed of small grains
with a poikilitic calcite cement.

Underneath it we come to the Ashbed or navite type proper. The comparatively large olivines (1 mm.) continue. The feldspar is an andesite, in two distinct generations, the larger visible to the naked eye (1.4 mm. x 0.37 mm), the smaller not a third as large, the augite very small, as is shown in Fig. 19. The olivine, although large, is quite rare. The augite is in very minute light colored idiomorphic prisms. This bed occurs again at the top of No. IX, and here the underlying flows remain of the same type with somewhat varying amounts of augite, down to No. IX, 255. The flow below this, to 277 ft. has a somewhat granulitic augite and an interesting case of a [illegible] feldspar (S. 15615) with low extinction angles, surrounded by a fresher border with the extinction angles of labradorite. It is a reversion to the melaphyre porphyrite of more basic habit.

([illegible] ft.) No. IX, 279. The underlying scoriaceous conglomerate has a genuine fine grained ash bed on top, as is shown in Pl. VI, fig. 1, S. 15417. The conglomerate is composed of amygdaloidal and microlitic fragments, with calcite. Underneath it we have repeated the cycle from a navite with very little augite (Pl. VI, fig. 4), and associated amygdaloids of the same character, to a more augitic melaphyre porphyrite in which the feldspar varies from andesite to labradorite, farther down. The same beds are repeated at the top of hole No. VIII, down to 178.

The beds from No. VIII, 190-377, show a return to the ophite type, only the upper one showing andesite feldspar; (1536 ft.) the rest going back to labradorite.

No. VIII, 377. The succeeding bed, a sandstone, consider- (1557 ft.) ing its thickness, is notable for its fine grained character, only the lowest foot being conglomerate; it is mainly composed of rounded grains of augite, of microlitic porphyrites, etc.

Two more small amygdaloidal melaphyre porphyrites, with low angled feldspars, inconspicuous augite or olivine, and glomero-porphyritic feldspar,—overlying four feet of shale,—bring us to another navite, which might almost be classed under the augite porphyrites, rather than under the melaphyres, though there is no important change in its mineral composition from the other navites except that the olivine is even more scarce. A curious feature in the bed is an aggregate of iron ore with agatoid bands of varying lustre (S. 15380). About eight of these flows of varying size, marked by a peculiar type of amygdules and amygdule fillings, bring us down to No. VII, 221, where we have a big flow of the melaphyre porphyrite type, ophitic toward the bottom, however, and containing a more basic labradorite feldspar. Similar types succeed down to ——
(2035 ft.) from top of cross-section.

No. VI, 81, = No. VII, 430. Porphyry tuff. Ash and (2045 ft.) sediment forms may be noticed, but the principal material of the bed is very uniform, being a quartz porphyry, with corroded quartz and oligoclase phenocrysts (S. 15237), not fluidal in texture, but with traces of perlitic texture (S. 15327). One fragment of microlitic porphyrite with quartz amygdules was noticed (S. 15242). This stratum, thin as it is, seems to be very widespread, for it is reported in the Peninsula and Tamarack mines. Does it represent the eruption which so interlarded the Beaver bay group with felsites, and produced the felsites of the Porcupine Mountains?

Beneath the tuff we have one small, and one large sheet of ophite, the Greenstone. The feldspar is throughout labradorite, the augite abundant, and the olivine and iron ores are abundant but small. There are also occasional big porphyritic crystals near anorthite.

(2310 ft.) No. VI, 363, the Allouez conglomerate, next below, shows beside the vesicular ash with altered glass fragments, i. e., pumice like those of Pl. VI, fig. 1, only porphyries with orthoclase and oligoclase phenocrysts. The sheets below for some distance belong all to the ophite family, though at times doleritic in texture. S. 15274 shows the poikilitic type well, the feldspar between the poikilitic augite patches being somewhat larger than that enclosed in them. The olivine is well marked.

S. 15275, from the same flow, shows the doleritic type. The augite is about half as large as in the ophitic type, in long octagonal prisms, while the feldspar is even larger than in S. 15274. The olivine is largely replaced by magnetite—rather coarser grained than the olivine which it replaces. Ophitic sheets continue with little variation down to No. II, 136. Thence we have a melaphyre porphyrite with more sharply defined olivine crystals, small augites, and a double generation (2570 ft.) of feldspar. This bed is associated with sediment in an ill defined manner. Then follow more ophites (in S. 15082 the olivine is porphyritic), largely amygdaloidal, down to No. IV, 108 at which there is a foot or more of basic sandstone largely composed of labradorite. Under this sandstone is a melaphyre porphyrite with porphyritic low angled feldspars,—one of the phenocrysts in fact seems to be orthoclase —then another foot of basic sandstone, then a thick very ferruginous ophite with labradorite, rather more basic than usual. Then follow a number of small amygdaloids, not as ophitic for their size as, for example, those in hole No. XI.

No. IV, 245-263, is melaphyre porphyrite. Then we soon have a big well-marked ophite. Then two small ophites and one big one, all more feldspathic than usual. Hole V shows nothing but ophites and their amygdaloids. Hole 1 begins in feldspathic ophites, with their amygdaloids. S. 15008 shows an interesting illustration of a big amygdule, the coarse grain becoming porphyritic, and interstitial glass and hematite showing around it.

(4006 ft.) At No. I, 361½, there is a change in the character of the flows, the feldspar being low angled, the augite in occasional polysomatic grains.

Next underneath comes an ill defined series of amygdaloids and sediments, the amygdaloid being of the porphyrite type; the sediment, which is well marked at the bottom, contains beside augite and plagioclase grains, poikilitic quartz and quartz porphyry and agate.

(4068 ft.) Beneath this comes a bed which is practically unique. Augite is barely present and in minute granules. Olivine is not present at all. Occasionally large oligoclase phenocrysts (2 mm. x 1 mm.) occur in a very fine grained and ferruginous groundmass of minute feldspars (0.20 mm. x 0.03 mm.); the latter are all low angled and many of them unstriated. Instead of the ordinary amygdules, this bed has minute irregular pores with borders blacker than the rock in general. S. 15120 is quite chalcedonic. At the Minong mine what I take to be this same rock has spherulites. We may then fittingly call it an oligoclase felsophyrite, classing it among the porphyrites, having affinities to the keratophyres, to the labradorite porphyrites, and to the quartzless porphyries in different directions, and itself varying somewhat. It may evidently be derived from the navites by still farther eliminating the augitic matter. The sheet beneath is in the upper part very much like the porphyrite, and in fact the line between the two flows is not well defined. At the bottom it is an ophite, not very basic. The observations in the field show that the two sheets tongue into each other in a very complex fashion, only to be explained by supposing, either that the porphyrite is intrusive, which does not seem likely from its contact with the overlying sediment, or that the flows were practically contemporaneous, and a certain amount of mixture took place along the contact line. This seems all the more natural, because the more acid flow being lighter would readily float on top. This supposition will also explain the coarser and finer streaks and the apparently corroded plagioclase crystals in S. 15052 (Pl. VI, fig. 6). The characteristic thing about the ophite of the lower bed,—the Minong trap—is that the grain is not as coarse as one would expect if it followed the same law as the Greenstone, and there is very little olivine in it.

(4174 ft.) Next underneath comes a heavy bed of normal ophite, then a foot of sand, largely labradorite, then a number of smaller amygdaloidal ophites down to 463 feet. Then comes a rather feldspathic ophite with a nest of augite (S. 15148) which brings us to the bottom of drill hole No. III.

No. XIII down to 230 shows ophites, feldspathic, yet having a basic feldspar near anorthite (S. 15718), and a couple of seams of red sandstone composed chiefly of augite and plagioclase granules. Then from No. XIII, 230-252, is a melaphyre porphyrite, with low angled feldspar and but very little augite.

Next comes a big ophite which is poikilitic but quite feldspathic, so that it is characteristic that the augite is cut up by the feldspar into wedge shaped portions which over considerable patches have common orientation, but the feldspar is quite basic, which may account for the augite retaining its xenomorphic character, which usually becomes lost when the augite is in small quantity.

Underneath this comes another big ophite, with a not clearly indicated separation of the feldspar into two sizes.

Probably connected with this is the fact that the feldspar extinction is frequently zonal, the zones having alternately greater and less extinction (S. 15767). In the doleritic spots the olivine is more abundant, and the feldspar not so much enclosed in the augite (S. 15770). Under this at No. XIII, 447½, comes a melaphyre porphyrite with small granular augite, occasionally porphyritic augite (S. 15775) and two not sharply separated sizes of feldspar. The pseudomorphs after olivine (?) are often like bastite. It is quite possible that they replace pyroxene. This is quite a characteristic bed and drill hole No. XIV begins in the same bed. The feldspar is quite basic toward the bottom. The flow beneath, from No. XIV, 139-200, leans more to the ophites, being in part poikilitic (S. 15792), and showing traces of a double generation of feldspar. Two feet more of basic sandstone bring us to a large and (5194 ft.) typical ophite. Below this bed (drill hole No. XIV, 367) comes in the Huginnin porphyrite, much like the Minong porphyrite (5260 ft.) (Pl. VI, fig. 5). The augite is rather easier to recognize, in the lower part only, however. The porphyritic phenocrysts are very much more conspicuous, and are a striking feature of the rock. The grain otherwise is given in Fig. 20, Chap V. This porphyrite would be a typical labradorite porphyrite, were not the feldspar oligoclase (Ab_4An_1).

Under this last bed is a little ash, and then a big ophite with olivine and feldspar nests. The feldspar in the poikilitic patches is much smaller than that outside. Fresh olivine occurs, but at the bottom of the flow it seems to be altered to magnetite, and (S. 15834) the ophitic augite is in long prisms.

Under this ophite at the top of drill hole No. XVI come a collection of feldspathic melaphyres, amygdaloidal and micro-litic with porphyritic feldspar, with the augite xenomorphic, occasionally somewhat poikilitic, but showing no great tendency that way.

(5849 ft.) Then at No. XVI, 438, we seem to strike into another oligoclase porphyrite or a conglomerate made up of the pebbles of the same, which passes into an indubitable conglomerate with calcareous cement and some quartz porphyry pebbles.

Under this is a large and well marked ophite, with the usual more basic feldspar at the bottom,—also zonar and nested feldspar (S. 15912), showing doleritic as well as ophitic texture.

(5996 ft.) No. XVI, 611, conglomerate with pebbles containing quartz (6003 ft.) phenocrysts, spherulites, etc.; under it is a melaphyre porphyrite with but little olivine, amygdaloidal and leaning toward the Huginnin type. Below the latter there is apparently a basic conglomerate with fragments of dark ferruginous, more or less microlitic porphyrites, and a cement largely calcareous; all the fragments are like the Huginnin porphyrite but the phenocrysts are not so distinct.

At No. XVI, 697, is an ophite with labradorite.

(6155 ft.) Under this a porphyry tuff. Corroded feldspar (Ss. 15948, 15949, 15950, 15955, 15977, 15987); spherulites (Ss. 15949, 15950, 15956, 15979); pores generally with dark borders and various fillings (Ss. 15950, 15951, 15971); perlitic forms (Ss. 15960, 15983) are characteristic. Fluorite is significant (Ss. 15972-6). Toward the bottom glass ash fragments, sometimes outlined with white chalcedonic margins, are not uncommon (S. 15982, Pl. VI, fig. 2); chalcedonic dots are characteristic of the whole formation (S. 15983). This tuff is very largely composed of fragments such as the underlying rock might furnish, and frequently in the forms of concave ash.

The remainder of the drill hole is in a red felsite with a secondary poikilitic groundmass in places, and very inconspicuous porphyritic crystals of corroded orthoclase and quartz.

CHAPTER VII.

TOPOGRAPHY AND QUATERNARY GEOLOGY.

§ 1. General description.

A glance at the map will show one that the archipelago of Isle Royale has a very strongly marked topography. The main features of it are so well outlined in Ives's description of township 67, range 33, at the northeast end of the island, and the main features of his description are so applicable elsewhere, that it gives me great pleasure to give the unpublished account of the first surveyor of the island, one who did his work honestly and well.

"This township (T. 67, R. 33), is all fractional, even to quarter sections and is formed of the points of the northeast end of Isle Royale, which have been compared by some to the fingers of a man's hand. There is but little resemblance to fingers except in the number of principal points or ridges which form three principal bays, northwest of Rock Harbor and are numbered from that northwest. These points are trap rock ridges, elevated from 20 to 260 feet above Lake Superior with courses neariy southwest by west and northeast by east (N. 56½° E.), and are sloping somewhat gradually on their southeast sides and have steep northwest escarpments, with many small broken cliffs the faces of which generally dip northwest about 80°" (i. e., like Monument Rock, Pl. VIII). "All of these principal points are points" (made up) "of points with rock ridge islands, continuing from many of them, which are narrow and similar in shape and course to the ridges of the point."

"None" (of these ridges) "except the largest ridge is over about 100 feet high, and that is about from 100 to 260 feet high and has a rounded and unbroken outline, with a steep northwest escarpment all of the way, and is a continuation of the principal ridge which passes through Township 66 North, Ranges 33 and 34 West. Rocks and soil are similar on the ridges through those towns and this. The rocks of all the ridges dip S. E. by S. from about 10° to 30° and 40° with uneven strata 1 to 3 feet thick. The principal splits run about S. 60° to 70° W. and N. 60° to 70° E., running a little obliquely across the ridges, and dip N. W. about 75° to 85°."

"Parts of the rocks have crossed courses or fractures and the largest ridge has them all the way. Many of the rocks are fractured into small angular blocks and some of them are very fine."

"The mineral veins are mostly in the splits or joints of the rocks, and are from a line to one and two inches thick, composed of quartz and other veinstone, which contains small particles of native copper in many places. The vein of the point between Rock Harbor and the first bay northwest is an exception to the others" (Scovill Point).

"The soil is a few inches to a few feet in depth, and all stony. It is deeper in some of the valleys and is mostly composed of the disintegrated underlying rocks, and rated second rate. There is a strip along the southern slope of the largest ridge, which appears to be good tillable soil of sufficient depth to be but little obstructed by rocks. A few narrow swamps may also be made good tillable alluvial soil by draining."

"*Timber.* All of the points and islands are thickly timbered with a shortish growth of fir, spruce, cedar, white birch, tamarack, aspen, with a thick underbrush, except on the largest ridge, of ground hemlock, spotted maple, hazel, mountain ash, alder, etc. The largest ridge has more white birch than the other parts, with some underbrush. The largest of the timber is about 12 to 15 inches diameter and the best is the spruce. The timber grows close to the water's edge, except on the outer points and islands, where the rocks are bare 20 to 150 links from the water's edge. The bays are mostly deep, vessels of any size may enter all of the large ones, and many of the small ones, and can pass close to the sides of most of the islands and reefs. Ridges were observed to continue from many of the points and islands under water for considerable distances and often near the surface of the water."

"Lake trout are to be found in all of these bays, and a few brook trout and whitefish."

"The variation of the compass needle is fluctuating over the whole township, but the most so from the summit of the largest ridge N. W. The extreme difference noted is 8° 0′ W. and 26° 40′ E."

§ 2. Adjustment of topography to structure.

The foregoing description is very closely applicable to all of the island lying northwest of the course of the Island Mine conglomerate. As we go toward the southwest end around Washington Harbor, there is distinctly more soil, as is seen for example in the records of drill holes Nos. IX and X. At the same time the dip of the rocks is a little flatter, being about 18° at the west or northwest end of the island and about 40° on Amygdaloid Island, at the other extremity. Along the length of the island, moreover, which has with an area of 210 square miles a length of 45 miles for the main island, or 57 miles counting the outliers, there is a slight change in strike, from N. 55° E., at the northeast end, substantially that given by Ives (Irving, N. 53° E.), to about N. 60° E. at the southwest end, which is the course assumed in reducing the drill cores to a cross-section (Irving, N. 65° E.). This slight change in strike and dip may be the cause of the cross fractures of which Ives speaks. These cross fractures are marked by breaks in the ridges, as frequently alluded to in previous pages. For example, in tunnel No. 1, of the Wendigo Company's explorations, in drifting N. an amygdaloid was found 26 ft. sooner on the west wall than on the east, and the vein and fault thus shown was plainly marked by a topographic break which Mr. Stockly has photographed (tunnel No. 1), and also carefully surveyed magnetically. It was supposed that the same break ran through a corresponding gap in the Greenstone. Again, near drill hole No. XII there is a topographic break, indicating a fault of which the evidence has been already given (p. 90).

We see thus that for the main part of the island the topography is very thoroughly adjusted to the rock structure. That structure consists in a series of sheets of ancient lavas, with very subordinate interbedded sediments, the parts more resistant to weathering being the centers of the large sheets, and the parts least resistant being the amygdaloids and sediments at the contacts of the flows. The watersheds of the islands are the central parts of these main flows; the main watershed between the northwest and the southeast part of the island being made by the largest flow that occurs, the great lustre mottled backbone of the island,—the Greenstone (Cf. Pl. XIII). The drainage then follows the valleys underlain by the sandstones, etc., and must depend for escape on cross valleys, unless it can continue to the end of the ridge at the end of the island. As we approach the southwest end of the island, where as we have said there is a greater depth of drift, the strict dependence of the streams on the ridges is not so marked, but still all the main valleys are genuine rock basins. From this we may infer that immediately preceding that invasion of ice which marked the Quaternary era, there was a period, lasting we know not how long, when the series of lava sheets which had been poured forth, solidified, and uptilted in the very dawn of geological history, were eroded and denuded until the topography was adjusted to the capacity of the rocks to resist erosion. We also know of this period that it was a period when the water level, the base level of erosion, was below the present level of Lake Superior, for we find all the peculiar and highly adjusted topography, with its valleys continuing out under the waters of the lake.

§ 3. Ice action.

At the beginning of the Quaternary the ice advanced over the island and cleaned off all of the preglacial soil, so far as we know, except so far as the clayey decomposed trap cut in tunnel No. 2 represents it. The evidence of its occupancy is found in the smoothed, polished and rounded surfaces, with grooves and scratches, apparently from the stones imbedded in the ice, which we frequently find. But here we have to put in a word of warning. In an island, surrounded by water which is frozen heavily every year, (as we shall soon see, practically the whole of the island has been exposed to the action of the waters of Lake Superior in the course of their gradual subsidence), the effect of this shore ice may be the same as that of glacier ice, so far as the smaller scratches are concerned. This was already noticed by Desor (F. & W., p. 203). Sometimes such scratches will occur where the cliff is undercut, polishing both the overhanging surface and the present water edge, and showing plainly that they could not have been produced by glacier ice, e. g., in an island of Siskowit lake in Sec. 29, T. 65, R. 35, and in the first mentioned costean (See Chap. VIII) near Ghyllbank. At other times, as in the cases figured by Desor, it is not quite so plain, and the general probabilities of the case must be considered. On the other hand the broader groovings, which often show interruption on a harder spot in the rock, can but be attributed to glaciers.

The ice overrode the whole island. I have not been able to recognize any material as morainal, that is, deposited by the ice directly, and not rehandled by water, although such may occur on the lee sides toward the southwest of the island, buried under rehandled material. The direction of the motion of the ice was evidently from the northeast and very nearly in the direction of the strike of the ridges but a little more from the east, so that the grooves run slanting slowly up the ridges, and one cannot implicitly trust the mutton backs or round ledges of rock rising from the swamps as indicators of the strike. Desor, however, made the strike of the striæ and grooves at Scovill Point and at Chippewa Harbor exactly the same as the bearing of Scovill Point. These observations are not quite in harmony with mine, viz.:

On Sec. 13, T. 66, R. 34, on the ridge of porphyrite south of Cold Run (F. & W., p. 85) and northwest from the Siskawit mine, the glacial grooves were very good and strike a little more east of north than the strike of the beds; their strike was N. 71° E. Close to the line between Sec. 9 and Sec. 10, T. 65, R. 34, glacial striæ strike N. 73° E. My observations seem to agree better with the observations of Desor, that the whole north side of the island is a lee side. Southeast around the head of Rock Harbor the strike is very much more to the north than the direction of glacial movement, but the topography still mainly depends on the nature and strike and dip of the rocks which make a swing to the south around the head of the harbor, with very flat dips. This structure is very evident in the steep slope to the west and gradual slope to the east. When, on the other hand, the beds are swinging back into line around Siskowit Lake the ice action seems to have more effect, and by its scoring to have brought out the conglomerate and sandstone in many places into more prominence. On the whole, however, we have no reason to attribute to the ice anything more than a moderate and superficial action on the topography.

§ 4. Lake action.

When the ice left the island, the latter was submerged beneath the waters of a great lake which lay along the front of the receding glacier. The evidence for this statement must be sought partly off the island. At Mt. Josephine, not far off on the north shore of Lake Superior, Lawson reports terraces up to 607 feet, and very well marked at 509 feet, and over on the south shore there are marked terraces around Hancock, up to 490 feet. Now, since only the highest ridge of Isle Royale attains to the altitude of 500 feet, and this only occasionally, it is evident that the waters which made the terraces mentioned must have covered the island, and at 490-498 feet we have a distinct terrace on the island. We have every other kind of evidence of the submergence of Isle Royale, growing more abundant naturally for the lower levels where the area of the observation is greater. We have numerous raised beaches, with sea cliffs, sea caves in amygdaloids, and skerries from the more massive rocks. The material, wherever opportunity to study it is given, shows rehandling by water, and boulders of foreign material are scattered over the surface as the flow ice of winter is wont to leave them. Let us mention a few of these features more in detail.

Raised beaches. These are quite numerous at almost every height above the lake surface, from those which are in direct continuity with present beaches, and run up 10, 15 and 25 feet, to those which are much higher and have no direct connection with the present beaches. The former might be attributed to some exceptional storm, if it were not that their pebbles are found covered with lichens, and even occasionally quite an old tree will be found clinging precariously to the cobbles. A good illustration of such a beach may be seen on Sec. 10, T. 65, R. 34.

The higher beaches and terrace lines occur very numerously all over the island. Whole hillsides are often one succession of faint benches as at the head of McCargoe Cove (Pl. IX.). A very noticeable thing is their dependence upon the local topography, the higher ridges being often scored by sea cliffs and terraces at about the height of an adjacent ridge which after it emerged would protect them from the force of the waves. For example, the Minong range where it crosses McCargoe Cove has a distinct sea cliff and bench at an elevation of about 90 feet, just a little above the ranges in front of it (Pl. XIII, cross-section G-H). So the most perfect raised beach I have noticed, as well marked and as bare of vegetation as those but 25 feet above the present lake level, is one that stretches as a barrier beach from one rocky point to another, crossing the little valley of a stream which has cut through it, close to the west quarter post of Sec 13, T. 66, R. 34. This beach is just about high enough (140 ft.) to have felt the full force of the waves unhindered by the ridge that makes Scovill Point, and striking, indeed, is this curving ridge of lichen-covered boulders which looks as though it had been deserted by the waves but a few years. Just at this level we find a number of evidences of a more permanent base level, and rather more action by the waves, for practically the same elevation (135 ft.) is well marked by a bench on the other or north side of Blake Point, and studies around Hancock on Keweenaw Point have shown that there, too, the subsidence from 150 feet to 90 feet above present lake level was comparatively slow.

Another evidence of the higher lake level is in the—

Sea caves. These are excavated in the amygdaloids or softer beds, generally, and may be well seen near the west end of the main island, on Secs. 26 and 35, T. 64, R. 39 (Pl. X). But the earlier explorers have made similar pits.

Skerries. This term is applied to those picturesque towers and jagged remnants of rock that are left when the waves beat and corrode vigorously a massive layer. The most notable instance of them in fossil condition, as we may say, is in the famous Monument Rock or Rocks.* The base of these rocks, (Pl. VIII and cross-section C-D of Pl. XIII) is about at the same level as the beach just above mentioned, and a few yards to the southwest of this we find other precipitous rocks, not so conspicuous, however, which as we go farther in the same direction, develop into a ridge with an exceedingly steep southeast side. When the lake was 140 feet, and more, higher than now the waves beat against the side of this ridge with the full force, not merely of the present Lake Superior, but of a much larger lake, and cut a marked sea cliff, while at the extremity of the point as it then was were the Monument Rocks as huge sentinels, outlying skerries. The top of these rocks is some 70 feet higher than the base, and since their top would have been worn off, if their emergence had been uniformly rapid from top to bottom, we are led to infer a rapid subsidence of the water in the first part of its fall, from about 200 feet down to about 130 feet. Of what happened thereafter we have no record just here, because the shore became that of a landlocked bay.

§ 5. Rapidity of emergence.

If we ask how rapid was this emergence, has it ceased, and what may have been the relative times required for its various phases, we shall find many qualitative indications, even though we are not able to make any numerical estimate

In the first place, the fiord type of coast even in very long and narrow and sheltered bays shows that the present lake level cannot have been maintained long, or these bays would have been filled up. So, too, the numerous streams which enter the lake with a rush, such as the outlet to Siskowit Lake, Sec. 31, T. 65, R. 35, and even more markedly the outlet of Hatchet Lake, on Sec. 12, T. 65, R. 36, close to the old Pittsburg and Isle Royale works, which is a regular cascade, would before this have cut back their courses and deepened their channels to more normal gradients. Moreover, the deltas of the streams are not large. One of the largest is at the head of McCargoe Cove, (Pl. IX). In general, however, the absence of extensive deltas from the coast line is apparent, even from a glance at the map, though the map does also show in some of the long and narrow lakes, blunt ends significant of partial filling. We may therefore conclude that the period of the present level is not, geologically speaking, long. For the last forty years or so, however, no material change has taken place in the lake level, for the floors of old adits along the south shore of Rock Harbor, were on the occasion of my visit in September, 1895, under 18 inches of water, showing that the water level was a little higher than when they were put in.* Nor is it surprising that the lake level should now be tolerably constant, for Lake Superior now drains over a rock threshold. (Cf. Crossman's Chart of the levels of the great lakes, 1859-1888, Milwaukee, Wis.)

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* **Also called Castle Rocks and Cloven Towers. Jackson, p. 422.**

When we come to consider the next question, that of the relative rate of emergence during different periods of time, the same arguments that tend to prove the recent date of the present level still hold good. Deltas at high levels are not conspicuous. The numerous ponds which are rapidly encroached upon by marsh plants are not yet filled up, in spite of a climate very favorable for such vegetation; frost has done but little to crumble down, and, as I have already remarked, vegetation still less, to cover over, some of these raised beaches. All signs point to comparatively little disintegration since glacial times, and my judgment is that the present shore line is more marked than any at higher levels.

If we ask whether the subsidence of the waters or elevation of the land has been uniform, the following table, No. VI, with the cross-sections, Pl. XIII, will give some idea of the more important benches and the levels at which the receding waters lingered longest.

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* This would not, however, necessarily indicate the other thing, viz.: a rise of water level, as such a change is well within the range of temporary, barometric, monthly and annual fluctuations.

SHORE LINES OF ISLE ROYALE.

[Mason's observations, 5 in. barometer, compared with one of equal size at camp. No corrections for temperatures.]

Location.	Observer.	Altitudes.				Character of features, and remarks. Terrace bench if not otherwise noted.
		0 100.	100 250.	250 460.	460+.	
Washington Island		20 25				
B. M. No. 62, N. of drillhole No. IX	Stockly, level. Lane			438 ft.		Top of southward facing cliff, sea cliff or fault scarp?
Beaver Island	Lane	10, 30, 60	95-115			Terrace and spit to S. W. cut in one bed, not structural.
Hole No. XV	Lane		92 120			Terrace accordant with structure. Fig. 12.
Island Mine	Winchell Lane.	 all around	95 mine	 315+		1881 84, Minn., p. 51. Granite boulders: terraces.
West end	Lane	10 20				Sea caves 10 ft. above water line, terrace at pocket beaches.
Todd Harbor	Lane Stockly, level.	30 36 81 90	130 140			
Trail, Todd H. to Siskowit L.	Barom. checked with Stockly's repeated readings. L.	30 36, 95	130 140. 180-200	312 372 -407 350	485?	Trail has been gone over several times with Barom. N. side of ridge, S. side of ridge less often; at 310 is very well marked.
McCargoe Cove						See illustrations, Plate IX.
Hawk Island	Lane	15				Raised beach.
Amygdaloid Island and Channel	Lane	15 30-40				Beach and sea cliff.
Hill Point	Lane	30 (estimated)				Well marked. Rounded cobbles very well preserved. Plate XIII.
Locke Pt.		15, 30, 35				Terrace.
Blake Pt., North side		30-55	139-140	272		Plate XIII, cross-section C-D; repeated measurements, terrace.
South side						Terrace and skerries.
N. W. of Siskawit mine	Lane	90-100	130 ± 10			Terrace. Barrier beach.

Back of Lea Cove		87				
Conglomerate Bay	Lane	10+40 20				Conglomerate shows well a terrace of varying altitude.
Chippewa Harbor	Lane	25, 35	109 or 140			Beaches, terrace, foot of rise at 123.
Around Lake Richie. Alt. 26 ft.	Mason	36				311 top of cliff. 275? flat bench.
Section 10, T. 65, R. 34		20				Lichen-covered beach. Old birch 20 ft. high down on it.
Siskowit Lake. Alt. 50 ft.	Mason	60	213			Terrace; streams swift, except from Mud Lake, around which the terrace goes.
Greenstone Range			210			Foot of sea cliff.
					462	Sea cliff.
				370		Swamp at foot of cliff.
					467	Terrace.
				383	490 98?	Terrace.
S. Side		85	138, 150 178, 194			
Siskowit Bay		30-40 14-20, 60-65				Terrace N. of bay near Hay Bay.
		95-110				Pt. Houghton, beach line.
Rock Harbor	Mason	30 and 60	203-211	308+		Sea cliff facing N. +terrace.
		96	204 127, 212			Terrace; at 195 it is steep,—on side of bluff; at 204 we are at crest of bluff, becoming less steep 40 ft. below; terrace at 127 ft.; crest at 212 ft.
		6 66 55, 96	135	380 410 456 430 404	472 485 510	Terraces largely according to structure? Cliff (271 ft. terrace is doubtful; a number of ridges near this level; bench opposite.)
				271		
		25				? at 25 ft. is top of sand spit, on both sides of head of harbor, referable in part to 30 ft. terrace.
S. of Sargent's Lake	Mason			250-280		Terrace.

An era of slow emergence will leave its impress in many shore lines. They will be few in an era of rapid emergence. Moreover in a period of rapid emergence becoming slower, or followed by a period of slow emergence or stationary level, the earlier part of the period is liable to have its marks destroyed by more extended work at lower levels. Let us study the records of the table above, with the object of more carefully considering the relative rate of emergence.

We have only two observations of terraces, etc., above 500 feet, while between 467 feet and 498 feet we find six, then down to 450 feet but one, and down to 400 feet but four more. Hence there must have been a very slow change of the water level when the latter was 485 feet higher than at present. This answers to that terrace noted by Lawson (20th Ann. Report, Minn. Geol. Survey, Part V, 1891) at McKenzie, his *series No. 32,* from 460 feet to 497 feet, and to that at 482 feet, back of Thunder Cape, which Upham (Bull. Geol., Soc. Am. vi., p. 23) correlates with the "Belmore" beach, though I am tempted to correlate it with the Duluth Boulevard beach, 485-490 feet, and the Hancock 490 feet terrace. The next halt for which we have noticed more than one record, is about 380 feet (3 records). Cf. McKenzie terrace at 379 feet and Thunder Cape at 392 feet, i. e., Lawson's Strand No. XV. Below this there is only one observation, 340 feet, (Cf. McKenzie at 347 feet), until we get near 310 feet, when we have four, indicating distinctly a pause after a rapid fall to this point. This is probably comparable with McKenzie, 320-326, or Nos. XXII-XXIII of Lawson's strands—and Upham correlates it as the Thibeault beach. For the next halt three observations agree very closely, giving an average of 273 feet (Lawson's Strands No. XXI). This terrace Upham correlates with his Double Bay beach. Then there is a marked gap (only one doubtful observation), that is, a rapid subsidence until the water level fell to 213 feet. Between this and 194 feet we have six observations. Back of the Atlantic mill and of Hancock we have a similar terrace at 210 feet. It is Lawson's XVII, Upham's first Beaver Bay beach (b). Then there was another rapid fall of water level, for until we get down to 140 feet we have but two rather peculiar terrace records. But between 130 feet and 140 feet the water level seems to have remained constant for quite a while (eight records),—the barrier beach back of the Siskawit mine and the skerries known as Monument Rocks being conspicuous instances of the effects of the water at this level. The back of the Hancock terrace is at this level, and much of the delta of Huron Creek, west of Houghton, may have been built at this level, which is recognizable on the hills back of the Southside location, west of Huron Creek. This is evidently Lawson's marked horizon XII and Upham's "Second Beaver Bay beach." The subsequent subsidence appears to have been somewhat slower, as the records below this point, are more distributed down to 85 feet, but much more abundant between 90 feet and 100 feet. This lower level would then correspond to the front of Hancock and East Houghton (90 ft.), to Lawson's VIII-IX, and the whole interval (140-90 ft.) to Upham's second and third Beaver Bay beaches, and to the broad sloping terrace on which the village of Hancock is built. Then there are no records between 70 feet and 80 feet and few below 90 feet, until we get to 66 feet. Between this and 60 feet there are a larger number of records, and the terrace is very well marked. This seems to be Lawson's well marked VI, and if so it would be the Chester Creek beach of Upham, but Upham makes the 90 feet terrace the Chester Creek beach, in accord with the theory of increasing elevation going north, and, as we shall see, the drainage of the island rather favors that theory. But on the other hand, the period of slow emergence indicated around Portage Lake and Keweenaw Point between 140 feet and 90 feet seems to be too well paralleled on the island at the same levels. Possibly the upper beach lines only have been much deformed, but to tell the truth so far as Isle Royale terraces are concerned, I have seen but little evidence of unequal elevation in comparison with Keweenaw Point. However, my observations were not made with this particularly in mind. Traces of shore lines are scarce below 60 feet, down to 30 feet. Here there is a distinct shore line, in places continuous with the present beach and connected with old sand spits at the head of Rock Harbor (Lawson's IV. Taylor's Nipissing Beach?*). Below this the beach crests are at all levels, but there are many observations at about 15 feet, more than between 30 feet and 20 feet.

On this question, interesting from a theoretical point of view, whether the emergence of the land is due merely to subsidence of the waters, or to an actual elevation of the land, not in all places to an equal amount, it is well known that Lawson (*Loc. cit.*, p. 286) and Warren Upham

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* While this volume was passing through the press Mr. Taylor visited the region of Port Arthur (Am. Geol., August, 1897, XX : 111) and identified the 63 foot beach as his Nipissing, and the levels from 400 to 450 feet (instead of 485 feet, as we make it) as his Algonquin. He agrees with Upham in assuming differential elevation.

(Bull. G. S. Am. VI, p. 27) have come to opposite conclusions. Without presuming to decide the questions on the altitudes of raised beaches given, for I think barometric observations too rough in their nature to decide, I would remark that the hypothesis of differential elevation implies certain effects on the stream drainage, which should be evident on Isle Royale, as it lies in long ridges in the direction of the ice advance and retreat.

§ 6. Drainage affected by unequal elevation.

According to Upham's conception, as the ice retired the land rose, the amount of the rise being greater to the north and northeast but the period of rise later. Hence the tendency of the streams as the land emerged would be to flow to the northeast rather than to the southwest, but as the elevation continued and as the northeast rose more, their gradient would be checked, and there would be a tendency to the formation of ponds and swamps. Whereas streams, formed on a natural declivity such that at the start they flowed southwest, would have their grade accentuated, and would tend to have fewer ponds.

Now let us apply some tests to Isle Royale. The dividing line between ranges 35 and 36 will do sufficiently well to separate the island into two halves, the one to the southwest and the other to the northeast. The former should show the one style of drainage, the latter the other. Now in the southwest half we have longer streams and fewer lakes, and of the seven lakes there all but Lake Feldtmann drain to the northeast, as would be expected if they were due to "ponding back" by northeast elevation. In the northeast half we have thirty lakes and more.

Of the streams, Cold Run, entering Tobin Harbor, I know to be very sluggish, and even where it crosses the east section line of Sec. 14, T. 66, R. 34, it is but little above the lake.* The stream entering Conglomerate Bay is also in a marked valley and starts from ponds, and the stream flowing northeast across the northwest quarter of Sec. 6, T. 66, R. 33, is also ponded as Upham might desire. Many of the ponds, however, drain to the southwest after all, and finally escape through cross valleys. On the whole the drainage is not at all unfavorable to Upham's idea, for this drainage of the waters sidewise, if an opportunity was offered, might be also expected in case the mouths of the valleys opening northeast were raised higher than their heads.

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*This indicates some error on Foster & Whitney's barometric section across the island. Cf. cross-section E-F of plate XIII.

A fuller test could be made by considering the courses of the swamps also, and we can easily see that there is here an attractive field for farther investigation, and detailed study of the drainage. For example, the stream entering at the southwest end of Siskowit Lake, enters sluggishly through a marsh, while that at the northeast end comes in on the run, which agrees with Upham's theory. But on the other hand Grace Creek, flowing southwest, has a *sluggish* flow in a broad valley. So according to the theory, Angleworm Lake might once have drained out into Tobin Harbor. There would be a fine chance to test the theory by searching for traces of such a channel on the divide.

§ 7. Surface materials.

To enter into a detailed description of the rocks whose fragments make up the gravels of the island is foreign to the purpose of this report. The bulk of the materials seems to be referrible to the rocks of the island. But similar rocks occur all around Lake Superior. Hornblende schist and other erratics from the Huronian rocks are however not uncommon, even at considerable elevations. Stockly has seen granite boulders on top of the Greenstone range, near Lake Desor. Near the Island mine are some conspicuous granite boulders. Granite boulders are mentioned by Desor at a height of 200 feet above the lake (F. and W., p. 201).

Back of Ghyllbank is a large boulder of a quartz porphyry, and along the ridge about 116 feet above Lake Superior are boulders of gneiss, hornblende schist, etc. (p. 196). On some of the lower levels fragments of Silurian limestones and cherts have been noticed.

CHAPTER VIII.

STRATIGRAPHY.

§ 1. Explorations near Washington Harbor.

One of the most important things to do is to put on record the developments of the explorations by costeans or trenches of the Isle Royale Land Corporation, as they soon become covered. We begin at the west end of the island, the costeans there being located more exactly on the map, Pl. III.

Beaver Island, foot of costean 30 feet* above lake and (76 steps) 200 feet west from northwest corner of Sec. 32, T. 64, R. 38. Twenty feet up is the first rock exposed, the bottom of which is a small, fine-grained amygdaloid with laumonite (Sp. 14794); below that the trench is already caved in, but there was an amygdaloid in it (Sp. 14793) † of which pieces are numerous.

Higher up, the rock is very fine grained and compact and remains so up to 35 feet greater elevation (Alt. 65 feet). Then we go 80 feet back on a terrace to another bluff which is at bottom minutely mottled (Sp. 14795), and the bed joints dipping 18°, but gets coarser for some distance as we go up. The top of the costean is on the section line between Sec. 31 and Sec. 32, 115 feet above the lake. The course of the costean is N. 50° W.; magnetic variation 26° E. The upper part of this costean seems to develop the big ophite at the bottom of drill hole No. II, 631, and from top of No. IV down to 40 feet.

Section 32. On the shore opposite Beaver Island, to the southeast, we have another costean close under the Greenstone range. Leaving the shore, for 30 steps the surface is flat and covered. Then we have steep cliffs and the exposures are located by their barometric elevation.

At 35 feet, an amygdaloid.

At 55 feet, trap; dip of bed joints 25°.

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* The elevations given in this chapter are estimated, or derived by barometer, and are above Lake Superior.

† Sp. refers to *hand specimens* in the collection of the Geological Survey of Michigan, not to *thin sections*.

From 105 feet to 125 feet, frequent apparent flow junctions, all amygdaloid (Sp. 14798), like numerous similar belts in drill hole No. II.

At 145 feet; up to here mottled, weathering to a coarse meal, and also spheroidally.

At 155 feet, apparently ten one-foot flows (Sp. 14799), then all mottled melaphyre; decomposed detritus at top of costean. This series is very easily matched in drill hole No. II, e. g., at about 57 feet and also lower down.

Ghyllbank. In this neighborhood on Sec. 29 were a number of trenches,—

(1) On trail running northeast from Ghyllbank about 500 steps west and 200 south of the east quarter-post. Beginning at the northwest end and going S. 30° E.,—at 110 feet (40 steps), amygdaloid,—going farther 154 feet, we come to a bluff of mottled melaphyre, ice-scratched and showing stratified talus sloping steeply away; dip of joints about 20°; underlain by fine grained porphyrite. It is planed and rounded, but scratched in more than one direction (Cf. p. 183). The bluff faces toward N. 65° W. and the scratches dip on a line toward N. 25° E., in one case down hill, being scored on a nearly vertical surface.

For 33 feet farther on, the ascent is very steep, the mottling growing coarser, then we have for 22 feet more a gentler slope to summit, the grain getting finer. Altitude of top of trench above bottom, 30 feet by Locke level. The ophite at the top of this costean is in line of strike from, and appears to be the same as that exposed on, Beaver Island.

(2) Fifty feet west of Stockly's station No. 6 *, running 200 feet down hill toward N. 30° W. (Pl. III).

(3) Three hundred thirty feet northeasterly (120 steps), a costean at an altitude of about 116 feet, running S. 30° E., on the first marked ridge north of the Greenstone, which falls slightly to the east.

Sp. 14726; on the summit of the ridge is a fine grained trap, amygdaloidal in spots, not lustre mottled, light grey, porphyritic on weathered surface while the fresh surface appears dark.

Sp. 14727; after about 20 feet the outcrop becomes very irregular in the character of the rock, continuing to about 33 feet, after which the ground begins to fall.

Sp. 14728, about 70-80 feet farther on, is from a rounded outcrop of amygdaloid, obscurely scored parallel to this ridge.

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*The table showing the exact location of this section was not accessible to the Survey.

(4) Seventy-seven feet farther, on the northeasterly trail, a costean to the northwest.

Sp. 14729; from the crest of ridge which here has obscure mottling; the outcrop is opened up 20 feet farther to the northeast. There is a veining disclosed in the trench, dipping 80° to northwest, running with the strike of the formation or a little more to the north (Sp. 14730 is part of the prehnitic vein rock, while the country rock is of same type as Sp. 14726). Going northeast, in 55 feet more we meet a boulder of hornblende schist and one of gneiss in the coarsely stratified drift; the outcrop still continues and is a massive fine grained ophite (Sp. 14731), and after 44 feet more there is another pit. The rock in it is red, decomposed, amygdaloidal (Sp. 14732) and riddled with clay and prehnite seams like Sp. 14730.

(5) Another costean, 20 feet farther on; to the northwest it shows massive ophite and 7 feet off from the trail to northwest crosses a vein; the costean also runs 66 feet to southeast, showing amygdaloid at the south end. There is considerable prehnite with copper in this exposure.

It is 858 feet from the last point along the bluff to the Lake Desor trail which is struck about a quarter of a mile (498 steps) from the clearing around Ghyllbank.

These exposures show more copper than any others which I have noticed in this region. There is nothing very characteristic about their rocks. They are not far, apparently, from the horizon of drill hole No. II, 554 (2942), which is also very much charged with prehnite and carries some copper, but I am inclined to take this as due to the fact that both localities happen to be veined.

Besides these costeans, there are three on Sec. 20, T. 64, R 38, near the southeast corner, on the northwest flank of the same ridge as that in which is drill hole No. I, exposing the same mottled melaphyrs, i. e., ophites, and soil of fine gravel with occasional well rounded boulders.

Then at about 1000 steps north of this corner, as per map of Wendigo property (Pl. III.), there are three trenches on the north side of the ridge in which is drill hole No. III.

Then at about 300 steps farther north, as noted on the same map, there are a large number of costeans developing the Minong trap at its southern edge, and there are also a number along its northern edge. These enable us to trace the Minong belt with great accuracy for nearly a mile, and it is practically outlined on the map by the trail to the various costeans which runs along the top of this ridge made by the Minong trap. As thus indicated, the strike is almost precisely one north to two east or N. 63° 25′ E., but since there are faults which seem to throw the outcrop to the southeast as we go northeast, the strike found instrumentally by Stockly, of N. 60° E., cannot be far wrong. The Minong trap is also developed by tunnel No. 5. The dip I measured there is 15°, in close harmony with that derived from the drill records (Chapter III, p. 84). An interesting feature developed, is a curving of joint and flow lines to the southwest, as we look at the trap from the northwest, and to the northwest as we look southwest (Fig. 25), apparently indicating a flow of the trap to the west, which is in harmony with the general law that the traps thin to the southwest. The strike observations in the costeans are disturbed by large magnetic variations. Some nodules of calcite and copper may be observed at the bottom of the trap.

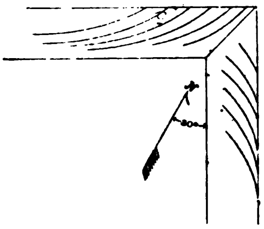

Fig. 25

Illustrates the curvature of joints in the Minong trap.

Of the other explorations of the Wendigo Copper Company as indicated on the map (Pl. III.),

Tunnel No. 1 branches and is very irregular in its course. It is in the gap made by a fault which it cuts, and is in the beds at the top of, and just above, drill hole No. III which is near it. According to Stockly, the amygdaloid is met in the tunnel, on the west side first, and then 30 feet further north on the east side. If these two amygdaloids are one and the same, the fault has changed the character of the throw from that between drill holes No. XVI and No. XV. There are, however, a number of very similar amygdaloids in drill hole No. III, at 275 feet, at 298 feet, etc., at about this horizon. Suppose, for example, that instead of the amygdaloid, drill hole No. I, 298, being thrown back on the east side 30 feet horizontally (i. e. 8 feet perpendicular to the bed), it were thrown forward as indicated for the throw between No. XV and No. XVI, about 50 feet. Then the amygdaloid of drill hole No. I, 362, would appear some 12 feet perpendicular to the dip, below No. I, 298, which may be the amygdaloid we see on the east side, as the discrepancy would be only 4 feet, and the boundaries of amygdaloids are not sharp, and with a 14° dip a slight variation in the dip or level of measurement makes a great difference in horizontal equivalents. Around drill hole No. III the master or bed joints make a dip of 24°, steeper than the true dip, as usual.

Tunnel No. 2 runs first through clayey soil, then into mottled decomposed red melaphyre, massive, non-amygdaloidal (at least with rare amygdules) and zeolitic. It is 60 feet lower than the top of drill hole No. IV and is in the second big ophite which occurs in that hole, i. e., from 40 feet to 108 feet. The decomposition is almost surely preglacial and indicates very little glacial erosion in such sheltered spots. It may be due to a fault, as we have indicated on the cross-section.

Above tunnel No. 2, half way up the hill, a costean and tunnel show amygdaloid above massive trap, as around drill hole No. IV, and at the extreme top of the hill the rock is thin-bedded and amygdaloidal. Drill hole No. IV stands at the top of the hill.

Tunnel No. 3 is driven only a little way, into a very well marked red amygdaloid. It is on the same level as tunnel No. 2, and would apparently strike the same formation. This is one of the indications of the fault drawn upon the geological map.

Tunnel No. 4 is within a few feet of tunnel No. 6, and was driven only a few feet.

Tunnel No. 5 is in an amygdaloid of which the Minong trap forms the hanging wall, as already described in the records of drill holes Nos. III and I.

Tunnel No. 6 is only ten feet or so in rock, which is laumonitic, seamed, decomposed and rather more broken than at tunnel No. 2; both of these tunnels run a good way through clayey sand. The ridge back of tunnel No. 6 is said to continue some two miles. Tunnel No. 7 is on the side of the Greenstone range (Sp. 14735).

§ 2. Explorations near Todd Harbor.

The other place where work was done by the Isle Royale Land Corporation was at Todd Harbor on a series of trails radiating from a camp known as Haytown (Pl. XI.). The location of these costeans in relation to the rock series generally is shown on cross-section, I-J, fig. 26. From this section it is apparent that they are largely at the same general horizon as those around Ghyllbank, above the Minong trap and below the Greenstone.

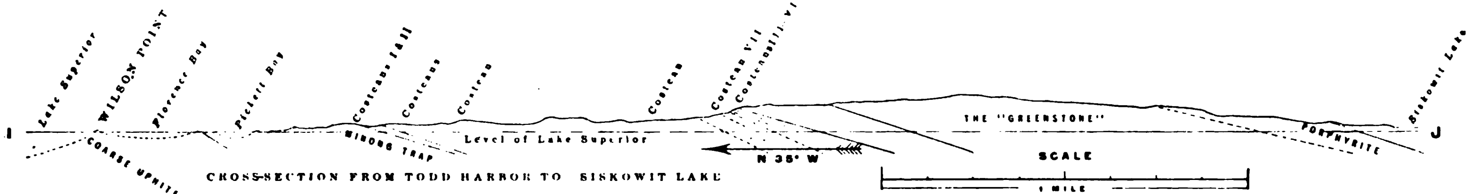

FIG. 26

Cross-section I-J along trail from Todd Harbor to Siskowit Lake. See Plate XI.

Costean No. **I.** The first costean we describe lies on the trail which runs southwest of Haytown over the Minong range at about 1550 paces west of the east line of Sec. 11, T. 65, R. 36. This costean is about 100 feet above Lake Superior and runs to the S. 15° W. with a spur to the southeast. For 110 feet (40 steps) the rock exposed is a fine grained, compact trap, then 20 steps more to the top of the ridge, then 10 feet more to where the costean forks and for 66 feet more the latter remains in the same kind of rock. On the spur to the southeast after 30 feet the red porphyrite, the same as occurs at the Minong mine, begins on the surface; 44 feet more brings us to a swamp and 143 feet across the swamp to a ridge of mottled melaphyre as in costean No. **II,** hereafter described. Going north from the north end of the costean 120 feet we notice a fine mottling, and in 44 feet more reach the foot of the bluff some 20 feet lower.

Continuing southwest, we notice along the trail a pronounced jointing running N. 30° E. and also the contact of the red porphyrite and the finer grained trap. The red porphyrite often shows flow lines. Over in section 10 we come to,—

Costean No. **II.** This was dug in 1889, and runs southeast across the range. Reckoning from the south end, we have,—

Eighty-four feet, mottled melaphyre.

Forty-four feet more, glacial marks running N. 60° E.

Sixty-six feet more, to top of ridge; altitude 150 feet.

Forty-four feet more, drop of 10 feet in altitude to about 140 feet.

One hundred forty-three feet more, beginning of second rise; glacial scratches, nearly horizontal, strike as before.

Twenty-two feet more, slope of red porphyrite and ophite mixed; dip 20° (?).

One hundred thirty-two feet to trail (Alt. 160 feet),—with a 60 foot to 40 foot bare bluff of a compact hard trap that shows perpendicular jointing, occasional large porphyritic feldspars, agatoid seams and minute mottling; apparent dip to S. 35° E. (magnetic). From this trail it is about 500 feet to a stream flowing northeast (Alt. 100 feet): thence 275 feet to a terrace on the southeast side of the ridge (Alt. 140 ft.); 210 feet more to the top of the ridge which shows a coarse diabasic structure, (Alt. 170 feet); thence 176 feet, down to a terrace at the foot of the ridge; thence 209 feet to the first ledge of rock and first terrace, about 200 feet above water; thence about 275 feet to shore.

This section, we see, gives us the Minong beds and the ophites immediately over and under them. Some old (? Indian) digging near costean No. **I** is said to have been found.

Costean **A.** On the trail southeast from Haytown, the first trenching is to the southwest of the trail, on the first ridge southeast of the Minong range, represented by Sp. 16037, with characteristic agates and red felsitic rock. Beginning near the center line of Sec. 11, the first 20 feet show spheroidally weathering mottled melaphyre (Sp. 16038), slightly amygdaloidal at top; then on the other side of the 100 feet (85 feet; Stockly) terrace is another rise with a finer grained and more laumonitic and seamed bed (Sp. 16039). The terrace corresponds in altitude to the top of the Minong range.

Costean **B.** Then on the next ridge, S 70° W. of the trail, we have a costean 200 feet long, 114 feet and 50 feet at its northwest and southeast ends, respectively, from the trail, showing the contact of the two flows,—a mottled melaphyre underlain by an amygdaloid. The contact is 20 feet, and the top of the ridge 50 feet, above the northwest end of the costean, and for 100 feet further southeast the mottled melaphyre continues.

Costean **C.** Then a little further southwest, where the stream following a cross fault (?) cuts through the ridge, we have two successive ophites the lower flow being amygdaloidal at the contact and the upper flow being fine grained. The strike appears to be nearly east and west and wavy dip 45° (?).

Costean **D.** The next costean is on the next marked ridge to the southeast near the corner between Sec. 11 and Sec. 13, T. 65, R. 36, about 168 feet above the lake. The ridge is an ophite as usual, and the costean develops a disintegrated seam half way up. It is 187 feet from the trail and shows the bed joints dipping about 14° to the southeast. The next costean we meet is the so called Jumbo costean, No. **VII** but keeping the order of their numbers, we turn aside to,—

Costean No. **III.** This runs up hill to the southeast from a point about 1750 paces N., 1125 paces W., of the southeast corner of Sec. 13, T. 65, R. 36; the course of the costean is N. 36° W.; magnetic variation 50° W. There are 10 to 20 feet of mottled melaphyre north of trail; Alt. about 220 feet at trail (Sp. 16067).

Seventy feet horizontally farther on, the rock becomes slightly amygdaloidal; joint-dips 16° to southeast; strike N. 50° W.

The next 20 feet the same; (Sp. 16066).

The next 100 feet, red and green amygdaloid (Sp. 16065); dip about 14°; much laumonite.

The next 20 feet the trench is filled. This brings us to an amygdaloid at base of cliff; altitude about 230 feet.

Forty feet more to cliff; discontinuous coarse seam like Sp. 16058, about 10 feet up.

At 15 feet up the same texture occurs with chloritic amygdules, not mottled; (Sp. 16064).

Altitude about 250 feet, top of cliff.

The next 40 feet horizontally, heavy amygdaloid; red laumonitic band at the end of this distance; green with white amygdules.

Glacial striæ 5° N. of E. and mutton backs.

The next 50 feet, amygdaloid.

The next 30 feet, the same all the way; (Sp 16063).

The next 30 feet, covered (Sp. 16062).

The next 70 feet, amygdaloid (Sp. 16061).

The next 80 feet, covered.

Costean ends at top of ridge in flat country; altitude probably nearer 240 feet than 310 feet.

Costean No. **IV.** Runs N. N. W.—not more than 60 feet—from 300 paces N., 100 paces W., of the southeast corner of Sec. 12, T. 65, R. 36, at an altitude of 355 feet, beginning with,—

Twenty feet of horizontal ophite, then an

Eight foot perpendicular cliff (at 4 feet down, coarse seam; Sp. 16058), then 70 feet sloping down to about 325 feet; dips of bed joints, 11°, 12°, 17°, 18°, 23°, 9°, 8°; strike of other joints as follows; northeast, dip 82° to northwest; strike, east to west, dip 71°-78° to N.; strike S. 75° E., dip vertical. Twenty feet, steep slope to altitude 290 feet; amygdaloid alternating with fine grained trap in a very complex way (Sp. 16059 and Sp. 16060). Some copper but much laumonite; the remainder of the costean, some

One hundred and fifty feet, is not bottomed in rock.

Costean No. **V.** Runs N. N. W. from a point on the east line of Sec. 12, T. 65, R 36, 360 steps north of the corner. Rock like Sp. 16059 and Sp. 16060, found,—

Ten feet from head of costean (Alt. about 290 feet); the amygdules are irregularly scattered through fine grained trap, and as before there is some copper with abundant laumonite, also calcite, chlorite and quartz. The rock remains unchanged to the bottom of a steep slope.

The next 70 feet horizontal (Alt. 250 feet) is irregularly amygdaloidal and fine grained, not mottled; no distinct flow lines, although there are marked contacts and signs of a flat southerly dip. The section of this costean is practically a continuation of that of No. **IV.**

Costean No. **VI.** This costean is about 100 steps along the trail northeast from costean No. 5, and shows slickensides on a slipping plane running N. 65° E. (magnetic), dipping 46° to the N. W. The slickenside striations make an angle of 45° with the direction of dip (Alt. about 250 feet). They mark the beginning of an amygdaloidal texture. Above them the rock is massive, becoming mottled; below (Alt. 240 ft.) is probably the flow contact line. Taking costeans Nos. **IV, V** and **VI** together, we have a section of some 40 feet of mottled melaphyre underlain by amygdaloids. The top of No. **III** seems to be in the same belt of amygdaloids, but the bottom shows a mottled melaphyre underlying this belt. Not far from costean No. **IV** the stream which is below it falls over this lower mottled melaphyre.

Costean No. **VII,** the Jumbo costean, is located in the S. W. ¼ of N. W. ¼ of Sec. 13, T. 65, R. 36.

Beginning at the top,—

The first 10 feet perpendicular from the top (Alt. 333 feet; Sp. 16070) are in a coarsely mottled melaphyre, weathering to a gravel; then a horizontal terrace bench 20 feet wide; then,—10 feet vertical, more and more coarsely mottled ophite; then 110 feet horizontal and down to altitude 297 feet; along this terrace all mottle dmelaphyre, then—the rock growing finer grained (Sp. 16071)—down a very steep slope (equivalent to 60 feet horizontally) to altitude 272 feet, contact with red amygdaloid. Joints strike N. 55° E. and N. 65° E., dipping 15° to southeast, and amygdaloid bedding also dips 15°-20° to S. 20° E.

Eight feet further down is another contact and we have a series of amygdaloid beds corresponding to costean No. **III** (Sp. 16073), down the cliff to altitude 210 feet when we come to a heavy bed of ophite, i. e. mottled melaphyre, covered after 15 feet. This point is just about 200 feet above lake level, then for 370 feet the costean does not show rock, but in the drift there is much dark red shaly sandstone; then for,—

The next 60 feet horizontally, falling 4 feet, the bottom is covered, but the costean shows a section of horizontally bedded sand and gravel with water-transported pebbles. (In the ridge N. W. across the swamp at the end of the Jumbo costean there is, in sand and gravel, a small costean (**E**) that did not reach rock, at about the same level—1600 paces N., 1875 paces W., Sec. 13, T. 65, R. 36); then taking up the section below the covered stretch, we find 10 feet of chloritic amygdaloid (Sp. 16051), with a fine grained quartzose greenish seam.

At about 160 feet altitude, terrace;—a fine grained ophite which continues northwest for 80 feet horizontally, through 20 feet of vertical fall; then,—

Twenty feet horizontally; bottom of ophite, thin-jointed (Sp. 16049); underneath it an amygdaloid (Sp. 16048); then,—

Eighty feet horizontally, falling 3 feet; uncovered terrace of mottled melaphyre; then,—110 feet on terrace of mottled melaphyre, finishing with a 20 foot bluff (Sp. 16047). The bottom of a melaphyre is in a swamp, which Stockly's measurements on the adjacent trail made 126 feet above Lake Superior.

The position of these costeans, Nos. **III–VII,** is not far from half way between the correlation lines, (589) feet, the Island Mine conglomerate, drill hole No. X, 193, and (4097) feet, the Minong trap, drill hole No. I, 456, i. e., the costeans would be expected to correspond to a point in the column somewhere near 2400 feet below the top. They would then correspond with the record of the upper part of drill hole No. II, and lower part of No. VI and the costean south of Beaver Island, and it is easy to see that they have a corresponding topographic position, and are petrographically similar, though owing to the lack of any markedly characteristic bed, it is not easy to correlate them bed for bed. If the covered part of costean No. **VII** does really hide a sandstone, as the amount of sandstone in the gravel seems to indicate, it is probably the bed at drill hole No. II, 136–175. (See p. 76.)

We thus finish the description of the exploring work of the Isle Royale Land Corporation. A few suggestions, not meant by way of criticism, but as guides to farther exploration may be pardoned. In the first place it will be noticed that, with the exception of the drill holes, all the exploration is in a comparatively narrow belt below the Greenstone, thence down to the Minong trap. This horizon is that of the Phœnix, Cliff, and Central mines, but they all worked on fissure veins. But few of the fissure veins have yet been proven by the costeans. It is difficult trenching to rock in them as they generally lie in drift-filled gaps. None of the belts shown by the drill cores to contain specks of copper indicated on cross-section K–L, Plate II, have been followed back and opened on their outcrop, as the drilling was the last work done.

There are distinct indications that the copper is more abundant,—

(1) In the porous beds, i. e., near contacts,

(2) In the more decomposed beds, especially those which are prehnitic, and hence,—

(3) Near faults. For example, a conglomerate bears copper in drill hole No. XII, which did not show enough to be observed in drill holes XV and XVI.

Now, as we have remarked in the chapter on topography, the weaker, decomposed beds are generally in the valleys, and the faults are marked by gaps in the ridges. Hence scraping the sides of the ridges is likely to show and has shown little of value. The shore line has also been repeatedly examined. Hence the most hopeful way of exploring in the future would seem to be to sink short drill holes on the southeast sides of the prominent valleys opposite gaps in the ridges, and if the soft bed which produced the valley was impregnated with copper in the neighborhood of the fault which produced the gap, sufficiently to make farther exploration desirable, a shaft could be sunk or trenching done to the northwest.

The costean back of Todd Harbor seems to show that the Minong belt is not as rich there as farther northeast, but there has been practically no light shed on the extent and richness of the Island Mine conglomerate, except that it was not rich in the drill cores. Of all the drill hole records, that of the top of No. VII seems to show copper most frequently disseminated in beds of the Ashbed type.

§ 3. Northern rock exposures.

Turning now to the natural exposures, it is not worth while to recount every exposure, the results of which are summarized in the map, but it may be worth while to mention some of the important localities corresponding to the part covered by the drill cores, before proceeding to discuss more in detail the structure of the southeast part of the island.

Beginning again at the west end of the island, which looks as though it may have been mainly determined by one of the north striking faults, the lowest bed that can certainly be recognized is the Huginnin porphyrite at Huginnin Cove, with the large ophites that lie just above and below it and form the northwest front of the island. The west end of the island is made up of a series of points representing the more massive ophitic beds, while the amygdaloids and contacts are more rarely visible. The north side of Washington Island, Double Island and Johns Island are of mottled melaphyre and on the north side of Double Island is a basic conglomerate, while the south side of these islands is like the beds just above the Greenstone. A bed of labradorite porphyrite with large and coarse crystals of plagioclase in a fine grained matrix is a well marked feature here. On the north side of Cumberland Point there is a green feldspathic melaphyre porphyrite, with elongated chloritic flecks, which represents the Ashbed group, corresponding exactly to the massive bed of porphyrite (drill hole No. X, 426) immediately beneath the first scoriaceous conglomerate, i. e., the bed we have correlated with Marvine's No. 45. This bears magnetic S. 87° W. from the west end of Washington Island, or about S. 88° E. in true course. Then comes a jog in the coast where a considerable stream comes in behind a ridge, which may be taken as the termination of the ridge of melaphyre porphyrite. Then continuing out on Cumberland Point, S. 75° E. (magnetic) from the west end of Washington Island, is an outcrop of the ophitic type such as occur above the Island Mine conglomerate. South 81° E. (magnetic) from the same end is another low outcrop of similar rock. Then about three-fourths of a mile southwesterly we get the first outcrop of conglomerate which continues with but few interruptions around the point, and there are no signs of any more trap. In general the dip of the conglomerate is from 9° to 12°, but there are some minor undulations, and one small fold. It is not possible from these isolated outcrops to define the boundaries of the different parts of the series exactly, but it is evident that each of these parts can be recognized, and also that their thicknesses are less than those indicated by the drill holes. Estimates of the thickness by measuring from outcrop to outcrop are not very accurate, for we do not know the mean dip, and there is every sign of considerable cross faulting. One fault comes out on the south side of Washington Island and is well marked, but there are many others indicated by gaps in the topography and to some extent by shifting of the ridges. Hill's map indicates quite a number (Plate XII). We have put on our geological map merely enough of the better indicated faults to give an idea of their general character. In general the heave in any one does not appear to be above a few feet, though the aggregate may be considerable. The faults seem in general to be nearly parallel to the well marked, nearly vertical joints. These are quite conspicuous in the Cumberland Point conglomerate and run N. 5° E., magnetic. The question arises in connection with the nearness of the Cumberland Point conglomerate to the Greenstone range whether this proximity is due to the thinning of the intermediate trap beds, or to the dropping out of the uppermost of them, so that the Cumberland Point conglomerate may represent also some of the conglomerates cut in drill hole No. XI, or whether we have an unconformable overlap of a more recent formation, the thinning being due to greater erosion. Now there are some reasons for believing that all three of these explanations are partially true. The conglomerate contains numerous trap and amygdaloid pebbles, and even occasional agates such as occur in the traps. But dismissing the question until we take up the south half of the island, we see that it will be safer to estimate the general thinning of the formation from lower horizons, rather than from the assumption that the Cumberland Point conglomerate represents the same horizon as the conglomerate on the shore of Siskowit Bay.

Leaving the west end of the island and sailing along the northwest coast, we see that we are following very nearly the strike. The large ophite which comes just above the Huginnin porphyrite may be seen rising and falling, sometimes at the crest of the ridge and leaving room for some smaller amygdaloidal beds beneath it,—the thompsonite amygdules of which are abundantly collected on the beaches,—and again coming down to the water's edge. Small gaps in the coast seem to indicate faults, and at Todd Cove this front range is broken through. At Todd Harbor it forms Wilson Point, the outer protecting point of the Harbor being a very coarse ophite, the augite patches being 2-3 cm. in diameter. On certain parts of this point, e. g., Sp. 16022, 1480 paces N., 650 paces W., in Sec. 10, T. 65, R. 36, there are good illustrations of the coarser feldspathic and porphyritic streaks which are a feature of these coarsely lustre mottled ophites, or gabbros as they would be called by many. Most of the exposures around the harbor are of ophite, but the point between Florence and Pickett bays at 1150 paces N., 10 paces W., shows a contact at its northeast end with some sediment and a well defined dip of about 32° to the southeast (Fig. 26).

The attitude of the various joints also indicates about this dip. The exploratory work of the Isle Royale Land Corporation we have already described. Continuing southeast from the costeans, along a trail which runs diagonally across Sec. 13, T. 65, R. 36, we pass over a comparatively flat highland, with occasional benches, and outcrops of ophite whose occurrence and the coarseness of whose grain we have taken into account in locating the Greenstone on our map. It is not until we have reached the east section line of Sec. 24, in the same township, where the trail turns and runs south, that about 1580 steps N. of the S. E. corner we find a coarse diabase porphyrite with occasional large porphyritic crystals, a bed which appears to be above the Greenstone, and to correspond with that which passes through Double Island and Washington Island. Continuing south, the last outcrops, which are most extensive and characteristic, are from 530 steps to 430 steps north of the corner, and are typical porphyrites of the Ashbed type, with occasional round green balls, with amygdules often large and irregular, with shells of quartz, some white radiated mineral (prehnite?) and datolite (Sp. 16002-16005). The partly empty cavities show at times copper crystals. Continuing along the coast from Todd Harbor we see gaps in the ranges running nearly north but a little east and probably indicating faults. On Hawk Island we get a bed of sandstone representing one of the conglomerates of drill hole No. XII in our geological column, which gives a reliable dip of 26° toward S. 32° E. Neither the bed above nor that below the sandstone is distinctly mottled. The lower one contains some amethyst. The sandstone is dark chocolate colored and there are boulders of conglomerate on the island. Below the sandstone is a bed of trap more than 50 feet thick containing some amethyst and above it another more than 30 feet thick.

Coming to McCargoe Cove we encounter the largest break on the island. Artificial exposures of the Minong trap on the west side and natural ones on the east side give a good opportunity to estimate its displacement, and all the ridges clear through to the south side of the island appear to be shifted. Immediately to the west of the entrance of the cove the Huginnin porphyrite is well exposed, showing that we have on the whole followed along its strike, and preparing us to meet the Minong trap, which is here found to be at a proper distance from it. (See cross-section G-H, Pl. XIII.). I have already described the Minong mine. On the east side of the cove I was able to find no trace of the Minong porphyrite, though exposures are numerous,—another indication of the fault. Though the Huginnin porphyrite is not exposed on the east side of the cove, judging from the big mottled ophites which overlie and underlie it on the west side and are assumed to correspond with similar beds seen on the east side of the cove (which, however, is rather an unsafe deduction, as there are a number of similar beds at this part of the series), the east side is thrown north, as appears also to be the case with the Minong trap, but farther south the throw seems to be the other way. Amygdaloid Channe' may represent one of the lower conglomerates, but no sign of the bottom felsite has been seen here. The dip, however, is high as indicated by the jointing of the traps, and also by a thin bed of sandstone on Amygdaloid Island. The south side of Amygdaloid Channel has a very well marked terrace, and most of the exposures are of mottled melaphyres, ophites.

Coasting on, the Minong trap is again found, as indicated on the map and cross-section A-B, Pl. XIII, and in Blake Point we meet again the Greenstone, which has been tracked by a series of cross-sections, and proved continuous from the other end of the island.

Sections over Blake's Point show that it is skirted by the porphyrites on its south flank, as indicated on the map and cross-section C-D, Pl. XIII. Near the west quarter post of Sec. 13, T. 66, R 34, we find a valley, and exposures of conglomerate which we take to be equivalent in horizon to the red sandstone in drill hole No. VIII, 337 (=1524 feet of the column)

§ 4. Southern rock exposures.

On the south side of Rock Harbor we find outcropping on the island sandstone and conglomerates, which indicate that we are near the top of the Lower Keweenawan, and as the maps show, the south side of the head of Rock Harbor is lined with an alternation of sandstones and traps which appear to be tolerably continuous bands, and though, in view of the number and exact resemblance of the sediments on the one hand and the traps on the other and the gentle but variable dips, and variations in altitude, I can hardly hope to have connected all the isolated outcrops exactly, yet many of them have been quite continuously traced and the general arrangement cannot be far wrong. It is very noteworthy that while on the north side of the harbor the ridges show no sign of disturbance, near the head of the harbor on the south side the dips are very flat, at times not over 4°, and the strike, while of course difficult to determine with precision with such flat dips, veers around from southwest to south. This is not due to a mere flattening of the dip toward the center of the Lake Superior basin, for when we come to Chippewa Harbor we find the dips as steep as ever (cross-section G-H, Pl. XIII), but the strata appear as though wrapped over some large mass below. This suggests either that there is an intrusion below or that we are on the flanks of an old volcanic focus. As confirming these suggestions, we find on following the shore, that the traps dip lakeward all around the protrusion of the coast from Conglomerate Bay to Chippewa Harbor (Plate XIV), and that parallel to the dip are numerous apparently intrusive sills. These are a very curious feature, as they run almost as regularly as beds and are extensive and thin. Near the Saginaw Mine there are four such thin belts. Sometimes they are only an inch or two thick and I gather from them and from certain seams of indurated red clay, which near the trap is epidotic, the impression that the igneous action was submarine, and that it was as easy for the lava to intrude itself into the mud or to split up a previous sheet, as it was to flow out directly beneath the sea. Moreover the associated sandstones are very often fine grained and not conglomeratic.

At the entrance to Chippewa Harbor and back of the neck where the fishing station is, there is well marked faulting, and from there on to the middle of Siskowit Lake there is more evidence of faulting of considerable throw, than elsewhere on the island. The throw at Chippewa Harbor is given by Foster and Whitney as 971 feet "in a linear direction" (i. e. horizontally?). The little cove on section 19, T. 65, R. 34, about two miles southwest of the harbor, shows also a throw, and near the mouth of Siskowit Lake the conglomerate is apparently thrown—by the McCargoe fault—directly in the way of the amygdaloids. The exact contact is not exposed, as there is an interval of about 300 feet between the nearest outcrops. Comparing the exposures around Siskowit Lake with those around Rock Harbor, it is evident that, toward the southwest the traps are running out. For on the south side of the west end of Siskowit Lake there is a ridge of conglomerate much thicker than any around Rock Harbor that is equally coarse, and the breadth of traps above the range of melaphyre porphyrite is obviously much less. It would therefore be quite natural to suppose that the irregular relation between the conglomerate and volcanic series on the north side of Siskowit Bay is due to the disappearance of the traps or to an erosion unconformity, and the fact that the conglomerate is made up of pebbles of basic as well as of acid volcanics, plagioclase porphyrites, amygdaloids, diabases, etc., red carnelians, agates, and other secondary quartz pebbles, would strengthen the latter conclusion. But on the other hand the fact that the abnormal contact comes immediately in a line of disturbance, and the further fact that the supposition of an unconformity would involve an almost overhanging cliff, are arguments in favor of a fault contact, and the traps seem too thick south of the head of Siskowit Lake to disappear so suddenly. The shore of Isle Royale for the rest of the way westward is conglomerate and sandstone, and Point Houghton is made up of a great series of sandstones dipping at a considerable angle,—from 15° to 22°,—whereas along the north side of Siskowit Bay the dips are flatter. All around the bay there is a very prominent jointing nearly perpendicular, but inclining a little so as to dip to northwest and striking between N. N. E. and N. E. This jointing is thus very nearly parallel to the direction of the fault we have supposed. Another interesting feature is found on Hay Point in the shape of a large calcite vein striking N. 63° E., and dipping 25° to S. E. In other words its strike is very nearly that of the formation, but the dip is somewhat steeper. This is very much like the calcite vein also mentioned by Jackson and Foster and Whitney, near the entrance to Rock Harbor (F. & W., *loc. cit.*, p. 82) and indicates a kind of motion which is very difficult to detect, i. e., faulting along planes near the bedding. Turning now a back glance upon the region around Chippewa Harbor, we see that

(1) In increasing thickness of individual beds,

(2) In longer duration of the igneous action as indicated by unusual development of the upper part of the series,

(3) In greater disturbance by faults,

(4) In the presence of sheets apparently intrusive (and I may mention here that about 60 steps north of the southeast corner of Sec. 27, T. 66, R. 35, there is a small intrusive dike following various joints), there are indications that we are here at the nearest point on the island to an old focus of eruption.

CHAPTER IX.

CHEMICAL PROBLEMS.

§ 1. General chemical character of the series.

The chemical interest of the rocks of Isle Royale gathers mainly, in the first place, around the variation in the character of the melaphyres, and secondly around the processes of concentration by which the copper has been formed.

The red distinctly felsitic rocks are, as we have said, comparatively rare, except as pebbles in the conglomerates. Investigations into their chemical character may therefore be more profitably postponed until we can consider them in their original beds, e. g., in connection with the felsites of Keweenaw Point. There are, however, at least two beds on Isle Royale, beside the felsite at the extreme bottom of the series (whose outcrop would be at the bottom of the lake), which belong to the felsitic series, namely the upper Minong bed which is at times a porphyry of the orthophyre series, at other times more of a felsite porphyrite or oligophyre,—the other, the Huginnin porphyrite with much more pronounced and conspicuous porphyritic oligoclase crystals or phenocrysts. Leaving these and a few doubtful beds out of account, the rest of the series is composed wholly of beds whose essential mineral composition is similar. They have a plagioclase, some augite, altered olivine, and in some shape the iron ores. They are thus all entitled to be classed as melaphyres.

§ 2. Variation in the chemical character of the melaphyres.

There is a wide divergence in character among these melaphyres, a difference obvious not merely microscopically but to the naked eye, corresponding to the difference between the melaphyre ophites and the melaphyre porphyrites which we have already described. As we have said, the melaphyre porphyrites are lighter colored, incline to have a smoother, more conchoidal fracture and to be more pronouncedly porphyritic, through clusters of feldspar crystals. When they are coarse grained they are much more conspicuously feldspathic, the augite being hardly recognizable. The amygdaloidal pores are liable to be but partly filled and then often with analcite or quartz, while in the ophite they are generally completely filled with calcite, prehnite, laumonite, etc. Under the microscope, in the porphyrites the augite appears much less in quantity than in the ophites, and very often idiomorphic, the feldspar is oligoclase more often than labradorite, but the olivine is more conspicuous.

Now let us seek what chemical fact these differences express. Analyses I–IV are from the most typical bed of the Ashbed diabase porphyrite type, while V, VI, VII, are from a bed of intermediate character that occurs immediately above the former, and below the first scoriaceous conglomerate, which corresponds to Marvine's bed No. 44. Comparing these with other analyses of some of the more ophitic of the Keweenawan rocks (VIII–XIV), including one of the Greenstone, we see that the variation in the two types is not dependent on a great change in the percentage of silica. But I have already called attention to the fact that there is a greater abundance of augite in the lower part of the upper bed which manifests itself also in the size of the grain (p. 146).

There is, as we can see, a slight but uniform and perceptible increase in the amount of silica accompanying this differentiation and disappearance of augite, but obviously this is not the distinguishing feature and it is a stretch of language to speak of the one type as more basic than the other, in spite of the fact that macroscopically the augitic type looks very much more like what we are wont to call basic. The essential factor is the variation in the amount of lime (CaO) and soda (Na_2O). We know that the olivine crystallized out at a very early stage, while the magma was still quite hot and in motion, but the differentiation does not seem to be due to any settling of the olivine to the bottom. In fact the olivine is more conspicuous, and the magnesia (MgO) quite as abundant in the upper part of the flow. The olivine seems rather to have been more strongly attacked at a later stage, the more calcareous the residual magma was.

On the other hand, the presence of porphyritic feldspar clotted together (glomero-porphyritic) and consisting of oligoclase, is characteristic of these rocks, and such differentiation as we find indicated by Ss. 15515–15523 may be explained by supposing that we had originally a magma containing so much soda (Na_2O) that oligoclase, which is less fusible than labradorite, and therefore could form at a higher temperature, was early formed and rose to the top until the percentage of soda was so reduced as to form a more stable mixture, in which the lime and soda were in such proportions as to make labradorite, and the lime so abundant as to make augite the last silicate to form, while in the upper zone the sodiferous character of the rock was accentuated. This we may suppose all took place, to some extent at least, before the magma came to rest, in the earlier stages of cooling and at the higher temperatures. Then in the latter stages of cooling and at a lower temperature the olivine would be attacked by the calcareous magma to form augite.

Now the group of melaphye porphyrites—the Ashbed type—form one of the best marked horizons in our series and occur not merely in one bed, but in many beds of somewhat varying habit, and of more or less pronounced character, so that it seems probable that we should not look to any surface conditions, but to deep seated magmatic changes for their origin. It may well be that the change which produced the group took place while the magma was yet in the earth, even though in such cases as Ss. 15515 to 15523 the differentiation has continued even in the individual flow (See pp. 145-151).

One other question suggests itself. May the peculiar character of the relations of ophites and porphyrites be due to the intermixture of the two magmas? To this we can reply that the change from melaphyre porphyrite to the ophites involves no marked increase in potash (K_2O), nor in silica (SiO_2), as would be expected if the character of the former were due to admixture of a felsitic magma. Analysis VII, which is an ophitic rock carrying labradorite, has only a shade less silica than analyses III and IV, where the augite is in small idiomorphic prisms. The alumina (Al_2O_3) is distinctly associated with the soda in variation. The total amount of iron does not vary much and the relative proportions of ferrous and ferric iron appear to be mainly dependent on the state of the weathering, the green chloritic rocks having the more ferrous iron.* The lime and the soda are however very significant. They are inversely related, the more of one, the less of the other, and the more soda there is, the less augite there is. This is perfectly plain in studying the first seven analyses made for me. Now it must be remembered that three of these analyses are of samples from the same flow, and traces of a similar change in character may be seen in numerous other flows.

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* Or does the state of the iron determine the character of the weathering?

Number	I	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.	XIII.	XIV.
Reference No.	15537	15537	15533	15533	15515	15519	15523							
SiO_2	49.27	49.36	47.25	46.99	46.45	46.25	46.13	47.97	49.20	46.32	50.03	49.15	47.25	50.20
Al_2O_3	16.75	16.05	lost	18.47	16.60	18.39	19.79	15.56	16.00	15.95	15.38	21.90	31.56	15.43
Fe_2O_3	7.78	lost	lost	4.44	2.72	7.70	7.24		3.03	0.86	11.78	6.60		
FeO	4.86	4.84	7.19	7.24	7.25	3.52	3.79	12.41	7.10	8.92	3.90	4.54	2.29	13.79
CaO	5.47	5.66	9.61	9.53	6.32	12.19	11.43	7.07	3.44	10.23	5.39	8.22	15.39	5.47
MgO	7.44	7 27	5.94	6.03	9.21	4.65	7 27	8.28	6.98	4.08	3.60	3.03	0.27	8.62
K_2O	0.48	0.49	0.40	0.33	1.02	1.04	0.52		1.31	1.23	1.14	1.61	0.37	
Na_2O	5.42	5.31	3.42	3.87	4.05	3.76	2.55	6.24	5.06	3.56	5.01	3.88	2.52	4.75
H_2O				3.90	5.01	3.41	1.83	2.46	4.51	3.25	2.73	1.92	0.40	1.74
P_2O_5											(0.38)	(0.83)		
TiO_2									2.26	2.78		0.18		
CO_2	(0.92)				0.40	1.00	0.29							
Ignition Loss	3.72	3.81									0.98			
MnO	tr	tr	tr	tr	tr	tr	tr		1.17	0.89				
Sum	101.19			100.30	99.03	101.91	100.84	99.99			99.94	100.80	100.05	100.00
Sp. Wt.	*2.806			*2.901	2.781	+2.866	2.877			2.6 2.73				

There is generally a trace of MnO (included in summation with CaO.).

*Average of three observations each.

+2.874, 2.859, 2.869, 2.863.

I and II are check analyses sampled only six inches from the bottom of the most typical porphyrite of the Ashbed type.

III and IV are check analyses sampled respectively 16 feet and 19 feet from the top of the same bed, which is at the bottom of drill hole X, 426-483.

V } 65 feet from bottom.
VI } Flow varying from porphyrite, Sp. 15515 to ophite, Sp. 15523, drill hole X, 338-415 } 43 feet from bottom.
VII } 9 feet from bottom.

VIII. Fine grained, from shaft at Rock Harbor, 15 rods north of Ransom, (F. & W. II, p. 88.) On p. 87 they give a partial analysis of the wal of Shaw's vein, Isle Royale, 26.95% soluble in H NO_3 58.09% soluble in HCl, including separated SiO_2. Loss on ignition, 2.20.

IX. Eagle River section, Marvine's bed No. 87, middle of bed (Pumpelly, Proc. Am. Acad., xiii: 285; analyses IX and X by R. W. Woodward.)

X. Irving quotes p. 66 (misprint, CuO for CaO). Bottom of same bed as X; Sp. Wt. 2.73-2.75.

XI. Streng's "Melaphyr Porphyr," Irving quotes p. 277.

XII. Streng's (Duluth) hornblende gabbro; Irving quotes p. 270. This rock shows plainly fluidal arrangement of porphyritic feldspar, mainly oligoclase.

XIII. Anorthosite (822); Irving, *loc. cit.*, p. 438.

XIV. Greenstone, (F. & W. II, p. 38), summit of ridge at Cliff Mine, i. e., 100-200 feet above bottom of flow, probably.

Besides these, Jackson reports the analyses of anhydrous prehnite and chlorastrolite. Whitney reports the analyses of pitchstone, pectolite and wollastonite, (F. & W. II, p. 106).

Immediately at the upper and lower contacts the character of the rock cannot be so well made out, but appears to be intermediate. But about a third of the way from the bottom the feldspar appears most basic and the augite most abundant, while at an equal distance down from the top of the flow, feldspar and feldspar phenocrysts continue very abundant and oligoclastic (e. g. Ss. 15490–15501, 15509–15512).

From rocks like Lawson's malignites (Bull. Geol. Dep. U. Cal. I, 12, p. 337) and from the normal felsites, these melaphyre porphyrites are separated by a high proportion of soda to potash, though the per cent of silica is very similar. These melaphyres have also much more iron.

§ 3. Concentration of copper.

The second point of chemistry which I would like to mention, concerns the concentration of copper. The general paragenesis of the copper in the Keweenawan, having been fully considered by a previous Michigan geologist (Pumpelly, Vol. I, Pt. II, Chap. III), need not be repeated here.

A recent paper by H. L. Smyth is however of such interest as to deserve remark here, especially as it might otherwise probably be overlooked. An abstract is as follows:—(Science, Vol. III, No. 59, February 14, 1896.)

Basing his theory upon the paragenetic series worked out by Pumpelly (*loc. cit.*), he calls attention to the fact that the earlier minerals which preceded the copper are mainly chlorite and non-alkaline hydrous silicates. The later minerals "are alkaline, and are close contemporaries of the copper. Among them are apophyllite (a fluorine mineral), and datolite (a boron mineral)." From the conditions of formation of the separate flows and the intercalated conglomerates, each flow after consolidation was immediately subjected to surface weathering and later buried. The earlier non-alkaline minerals were, he conceives, produced by this surface weathering, the alteration progressing from top to bottom in each individual bed.

"Afterwards came the northerly and northwesterly tilting, and the formation and filling of the fissures, and the impregnation and partial replacement of the amygdaloids and conglomerates. The new minerals of this period are sharply separated from the alteration products of the first which they often replace, by their richness in alkalis, and the presence of fluorine and boron. The two periods therefore are far separated in time as well as by the character of the chemical agents at work, and do not, as Pumpelly supposed, represent a continuous march of alteration."

Prof. Smyth concludes finally that the copper was not derived from overlying sandstones nor from the traps themselves, but from a deep seated source, and that it was transported by ascending solutions, and probably precipitated as Pumpelly had suggested.

Now as bearing on the argument of this paper we may remark that the universal, and with rare exceptions, complete alteration of the olivine, even in these deep drill cores, lends weight to Smyth's theory that part of the alteration was independent of the present surface of the ground. Moreover, as we have seen, for a considerable thickness of the geological column there is no debris that cannot be considered of local origin, so that it is perfectly possible to suppose that the flows from near the bottom of the series to about the time of the Island Mine conglomerate were sub-aerial. The presence of fluorite also is another point which would tend to confirm his theory as to the action of fluoriferous and boriferous solutions in the mineralization of the beds. But on the other hand I confess I cannot believe in the great interval and wide gap that he supposes between the later copper-bearing and earlier silicates. If there is one mineral with which the copper is more particularly associated than with others it is prehnite, which is not boracic, nor does it contain fluorine so far as I know. Datolite is fairly widespread, but by no means a necessary accompanist of the copper, while apophyllite and analcite are rather curiosities than otherwise, and are said to occur on Keweenaw Point more in the upper levels, which is hard to understand, if they are of deep origin. Moreover the copper is undoubtedly more abundant, the more decomposed the rocks are, and the whole microscopic appearance is that the prehnite is as much a decomposition as an impregnation mineral. Moreover, as will be seen on reference to the geological column, the analcite seems to be especially associated with the more sodiferous melaphyre porphyrites of the Ashbed type. The presence of beds of strongly contrasted chemical character seems to favor the accumulation of the copper, and if the copper is of deep seated origin it is hard to understand why we should not see more traces of it close to veins in the basic sandstones of the Upper Keweenawan. Furthermore we find copper associated with the Triassic traps of the Atlantic coast, which are chemically similar, though so different in time and place of origin. I must therefore believe, without denying that deep seated thermal waters may have had a share in the process of concentration, that the copper is in the case of the Keweenaw traps derived by a process of lateral concentration. And, moreover, the fluorine and boron that are present are not more abundant, one would think, than might easily be accounted for by derivation from the original traps and the vapors immediately associated with their eruption. It is noteworthy that boron minerals are more abundant than minerals of fluorine, which corresponds to the fact that basic beds are more abundant than acid, for boric exhalation and minerals have long been known to be associated with eruptions of basic rock, and fluorine exhalations with those of the siliceous rocks.

CHAPTER X.

DIABASES, PROBABLY KEWEENAWAN, INTRUSIVE IN THE HURONIAN.

§ 1. Introduction.

It seems to be proper to single out for presentation now from among my descriptions of the rocks of the iron-bearing series, the publication of which has been delayed by various causes, that group which in all probability is the intrusive equivalent of the rocks whose descriptions make up the bulk of this volume—I mean the pipes and necks leading to the Keweenaw flows. It will be instructive to thus contrast the deeper seated and surface types, just as Iddings has done for the rocks of Sepulchre Mountain and Electric Peak. Since, in comparison with most of the rocks of the Huronian, they are not dynamometamorphosed, cut the formations up to the base of the Eastern sandstone, and are chemically nearly allied with the Keweenawan traps, the latest series of dikes found cutting the rocks of the iron country have always been considered as intrusive equivalents of the Keweenawan.* As such, therefore, they are equivalent to the intrusive "Logan sills" and accompanying dikes described by Lawson† from the north shore of Lake Superior, the latter standing in the same relation to the Isle Royale rocks, that the former do to the rocks of Keweenaw Point.

Inasmuch, therefore, as the general petrographic descriptions, of which these were a part, have been so long delayed in publication, and are not yet in immediate prospect of appearing, while monographs XIX and XXVIII which have been recently issued by the United States Geological Survey make their issue without considerable revision inadvisable, for many descriptions would be superfluous and many references should be inserted, the description of this particular group may well be incorporated in this volume to give an opportunity for contrasting superficial and deeper-seated forms of basic igneous rocks. There has been great confusion in times past between these kinds of rocks, which still continues. The American Geological Railway Guide speaks of copper being found in a great trap dike on Keweenaw Point, and, as we have seen, N. H. Winchell and I differ as to the presence of trap dikes on the north shore of Isle Royale (p. 150). Again, in the Minnesota Bulletin No. 8, on the Logan sills just mentioned, we find Lawson challenging the statements of various authorities as to the existence of diabase flows in the Animikie.

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*Geol. Surv. of Mich., Rominger, V., 1893, p. 6; Seaman in Wadsworth's report of the State Geologist for 1891-1892, p. 139; Bayley and Van Hise. 15th Annual Report, U. S. G. S.; pp. 516, 644.

†Lawson, Bull. No. 8, Geol. Survey of Minn. Also American Geologist, vii, 1891, p. 153. Also cf. Wadsworth, Bull. 2, Minn. Survey, and Mon. XIX, U. S. G. S. p. 349.

§ 2. Use of term diabase.

One word as to nomenclature. The use of the words diabase, melaphyre, basalt and gabbro, have been various. For us a diabase is a characteristically intrusive, not too coarse grained, rock of the same chemical composition, and essentially the same mineral composition as a melaphyre. The word "characteristically" is inserted to rule out small dikes intruded so close to the surface as to differ in no textural respect from a melaphyre. The rocks here included have textures which indicate clearly their intrusion. On the other hand the words "not too coarse grained," which I trust may be later replaced by a more exact definition, are intended to rule out the great massive "batholitic" intrusions which have been by common consent called gabbros. Thus my idea of diabase is a rock in small intrusions, in other words belonging under Rosenbusch's group of "Gang-Gesteine." I thus follow the road indicated by Rosenbusch on ,p. 520 of the second edition of his "Mikroskopische Physiographie," 1887, rather than the path he himself has followed in his third edition (1896, p. 1093) where he includes under diabase both intrusive and effusive types, and ranks the group among the "Erguss-Gesteine." But we have two terms already for the effusive forms of the gabbro magmas. What object is there in adding a third?

If it be granted that there is an independent and characteristic type of small intrusions, I do not fear severe criticism of my terminology. Criticism of my usage will come most forcibly from those who do not believe that the small intrusion can be distinguished from the effusion type, and interpret otherwise what I conceive to be characteristic textures. I presume Rosenbusch would gladly have followed the path which he indicated, if he had found that facts justified it. That he did not do so makes me doubt my own conclusions, but after all I can but present the case as I see it and leave time to judge the event.

CHARACTERISTICS OF SMALL INTRUSIVES.

The signs of effusion or of intrusion * may be looked for (A) adjacent to the rock, (B) along the contact, or (C) within the rock itself. It is only in case characters of this last type are present that we should be justified in giving different names to effusive and intrusive forms of the same magma.

(A) As regards the adjacent rock, (1) it is baked and new minerals of various kinds are formed, the well known phenomena of the contact zone. If these occur both above and below a sheet we are quite justified in regarding it as intrusive, whereas the sediment on top of effusive sheets shows little or no sign of contact action, though induration may be merely secondary and occur above a flow. (2) On the other hand the sediment above an effusive sheet (and below as well) may be partially composed of fragments of the latter, i. e., tufaceous. This is a sign of effusion. Friction breccias may occur above and below an intrusion and the overlying rocks may be fractured and disturbed as well as the underlying. An intrusive may enclose fragments of underlying rocks as well as overlying rocks and, generally speaking, its action upon them is more energetic.

(B) As to the contact:

(1) An intrusive rock is liable to send out fine strings and fingers, both above and below, into the strata between which it lies, and though it may follow the lines of sedimentation more or less, it is very likely to jump across from one set of bedding planes or cleavage planes to another.

(2) A flow is theoretically accordant with the bedding planes below if poured out beneath the sea. In the same way if not conformable with the beds above, the unconformity is an ordinary erosion unconformity, not one of intrusion, and the difference is often recognizable, in a number of slight marks for which no short general statement can be given. The characteristic clinkery "aa" surface or ropy "pahoehoe" surface of a flow is often recognizable.

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*Cf. Mus. Comp. Zool. Bull. XVI, 6, pp. 100–102.

(3) Sandstone veins or clasolites of fine mud, ramifying into the igneous rock, in wavy or contorted, or sometimes horizontal lines of stratification, are also a feature of effusives. They probably often fill shrinkage cracks.

(4) The flow lines and crystals formed before or during the flow are wrapped around the irregularities of the surface of igneous contact, i. e., the lower surface in flows, both surfaces in intrusive sheets.

(C) Among the characters of the rock itself we may mention:

(1) The generally more symmetrical character in a sheet or dike, especially as regards the jointing, which will be approximately the same for the two surfaces. This is not true in a flow. (Cf. J. P. Iddings, Am. J. S., 1886, xxxi, p. 321.) Amygdules, and variations in grain and probably variations in chemical character are also more symmetrically arranged in intrusions.

(2) We have shown above (Chap. V) that in so far as we may assume (a) that an intrusive sheet heats up its walls while an effusive sheet has them kept at a fairly constant temperature,[*] or (b) that an intrusive sheet is at a temperature much above that of solidification, while a flow comes down more nearly thereto, before ceasing to flow and solidifying at rest,[†] or (c) that the walls of an intrusive sheet tend to check the escape of gases whose escape promotes solidification[‡] the effusive rock, so far as the grain of its last formed constituents is concerned, will have a marginal zone of finer grain, which may extend to its center, but which will be narrower or wanting in the intrusive rocks, —in the plutonic rocks generally wanting. It may be wanting if the upper part of an effusive has been eroded away.

(3) If as above assumed we suppose the effusive magma to continue to flow as long as possible, there will be a larger proportion of crystals which will be formed during the period of motion and will show this by their fluidal arrangement, mechanical fractures, etc. (porphyritic texture).

(4) Gas bubbles cannot form under too great a pressure. Hence the vesicular (altering to amygdaloid) texture cannot be formed at too great

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[*] That the former condition is often true is shown by the baking effect on the rock outside. That the latter condition is also approximately true is also shown by the fact that lava fields have been walked on while the temperature a few feet below was glowing.

[†] The former part of this statement is suggested by various facts as to initial temperatures of lavas, e. g., the fact that the lava boiling up in Kilauea melts down the crust, while the latter part is obviously likely.

[‡] As the flow of gases follows the same laws as that of heat, the effect is the same as that of hypothesis (a), or if the walls are already saturated with gases or steam, it is equivalent to raising the temperature at the margin (i. e., having a hotter country rock) so far as this effect is concerned.

depth. This texture also implies glass. Generally amygdules are rare or absent in intrusions. In flows they are characteristic, often very abundant in the upper part, less so at the bottom of the flow where, however, elongate spike amygdules often occur at right angles to the contact.

(5) The production of glass requires a rapid cooling down below the temperature of solidification of the last mineral which would have been formed in case the rock had been able to crystallize completely. Hence if the walls of a sheet were not kept cold glass would not be so likely to form. In other words even near the margin intrusive rocks are less likely to be glassy.

(6) Toward the center of the flow or wherever the cooling was slow enough to allow complete crystallization to take place, in an effusive complete crystallization might take place until there was nothing but gas in the interstices (porous miarolitic, microdrusic or doleritic texture). These cavities might remain empty, or be filled in the ordinary way with secondary minerals of the zeolite or chlorite groups, or chalcedony or opal, etc., permeating the pores. In an intrusive rock such crystallization would be likely to go on until in the interstices there was a hot water solution of alkaline silicates and silica, which might circulate and react on the minerals previously formed, or be deposited in veinlike manner as micropegmatite. Such cavities could certainly not be empty, i. e., filled merely with gas, unless the intrusive were so near the surface that the pressure was not sufficient to keep superheated water in the liquid state. Thus there should be a difference between effusive and intrusive rocks, in the filling of the last interstices. (7) Furthermore, the retention of any gas, whether steam or other mineralizer, might be expected to somewhat modify the minerals that would be formed in the crystallization of a magma. Iddings (U. S. G. S., Twelfth Ann. Rep., p. 657) has studied this feature in a somewhat less basic group of rocks. The most essential difference that he found was the greater development of biotite and quartz in the intruded rocks. Hornblende instead of augite he also notes. Something similar may perhaps be noted in our rocks, for in the diabases, intrusive rocks, there is more marked zonar variation of the feldspar, and the quartz, though absent in the effusive equivalents, appears just as in the dioritic series which Iddings studied.

(8) Finally, there are differences in the relative sizes of the various constituents, which may be significant. The feldspar in the dikes seems

to be generally larger in proportion to the augite than in the sheets,[*] and this fact may be connected with the probably hotter initial temperature which we have suggested above for the dikes. For in that case the feldspar might get more of the benefit of the slow initial cooling, as may be seen by a study of Plate IV.[†]

We have given a number of characteristics of intrusive rocks. Not all these characteristics may exist in a given intrusive, for here as everywhere there are transitions. Nor is there any one characteristic by which we can identify every fragment of an intrusive basic rock. The interior of a large flow is not often glassy. The margin of a sufficiently small and sufficiently shallow intrusive may be. It will probably be well in time to replace the expression "characteristically intrusive", if the above definition is nearly acceptable, by the characteristics of texture or composition which we find most uniformly to indicate intrusive character, but it is hardly well to let the discussion of nomenclature blind us to our real object, which is to determine from the characteristics of a rock its origin and environment.

We pass then to the descriptions of the sections of the diabases to see how far we can recognize the characters above stated.[‡]

§ 3. Basic dike rocks. General description.

In these rocks a lime-soda feldspar whose cleavage faces show the well known twinning lines, lies in lath shaped forms running in every direction through a dark brownish gray to black mass, which the microscope shows is mainly composed of pyroxene. They are the youngest igneous rocks of the iron region, and cut every formation so far as known, excepting the Eastern (Potsdam) sandstone. They correspond closely with many of the effusive forms which we find in the Keweenaw series.

In the region about Marquette they run nearly east and west and cut the serpentine.

These rocks were probably included by Foster and Whitney in the correct general designation "trap dykes".[‖] Koch[§] as early as 1852 recognized that these traps were composed essentially of augite and labradorite, with a certain amount of magnetite generally associated in minute grains, and called them dolerite. This is almost equivalent to the name that we call them, the difference between dolerite and diabase being according to Rosenbusch one of age, and Rominger has retained the name dolerite.[*]

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[*] With the exception of the peculiar irregular streaks of doleritic texture in the sheets, excluding also crystals plainly formed before the magma came to rest.

[†] The zone of uniform grain of the dikes, Fig. 17, shows that the initial temperature being $0.784 = \widehat{n}/4$, the temperature of formation of augite must be somewhere between 0.600 and 0.250. If the temperatures of formation of the feldspar were in the interval between 0.784 and 0.600, the time of its formation between these temperatures might be much greater relative to the time of passage through the range of temperatures devoted to the formation of augite, than if the latter were nearer the initial temperature. However, we cannot say that this is the only factor concerned, for the feldspar in the diabases seems to have continued to grow longer than in the flows, changing its chemical character.

[‡] It may be well to remark that the order of investigation was the reverse. The descriptions were first written.

[‖] Foster and Whitney, II, p. 19.

[§] Studien der Goettingischen Verein Bergmaennischer Freunde, 1852, VI, p. 201.

In the meantime, however, Brooks and Marvine had taken a step in the wrong direction, afterward corrected by Wichmann, Allport and others,[†] by calling amphibole what was really augite, so that these rocks became "trappean diorite".[‡]

Wadsworth contemporaneously with the Wisconsin report recognized these rocks as diabases[§] and they have since been generally accepted as such by Irving, Williams, Van Hise, and others who have written on them. The subdivisions that I have found it worth while to make, in my larger material, have not been made by previous writers and are perhaps too minute. By far the largest number of the dikes of this group belong to the quartz diabase type (a term which Wichmann used) of which the others may be considered exceptional modifications.

§ 4. Enstatite diabase.

This peculiar type is known from only one locality, i. e., from a rock point on the west side of the big bay, Sec. 4, T. 51, R. 27. It is called trap in the field note book and appears to be from a dike cutting the granite represented by Sps.[¶] 698, 699. Sp. 693 is immediately from the contact and the others follow in the order indicated by their location. The south limits of the trap are covered with recent formations. This outcrop has not been studied enough to determine its geological relations, so as to know whether it is merely a modification of the quartz diabase group, as appears most natural, or of the peridotites. Wright named it serpentine.

Enstatite or bronzite has also been found rarely by Van Hise (U. S. G. S., Mon. XIX, pp. 350, 351, 354) in the diabases of the Penokee district.

The hand specimens are much alike and in general look like an ordinary diabase of fair freshness, except that here and there, not too abundantly, are sprinkled small crystals of enstatite of a yellow brassy lustre.

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[*] Geol. Sur. Mich., 1880, IV, p. 145, et seq.

[†] Geol. Sur. Wis., III, 1879, pp. 570, 621-627.

[‡] Geol. Sur. Mich. II, 1873, pp. 42, 51, 158, 176 to 179.

[§] Bull. Mus. Comp. Zool., vii, 1880, pp. 36, 39.

[¶] S., respectively Ss., is used to denote reference to rock sections, Sp., respectively Sps., to denote reference more particularly to hand specimens.

The ground is of a dark gray color and the feldspar crystals do not show much variation in size, being between one and two millimeters long and of the form and habit usual in diabases.

The specimens from this dike are all located from the S. E. cor. Sec. 4, T. 51, R. 27, as follows: 692, 1685 paces N., 645 paces W.; 693, 1800 paces N., 660 paces W.; 694, 1675 paces N, 625 paces W.; 695, 1620 paces N., 620 paces W.; 696, 1606 paces N., 640 paces W.; 697, 1600 paces N., 650 paces W.

NOTES ON THIN SECTIONS.

S. 692 is composed of chlorite, magnetite, plagioclase, with small interstices filled with quartz.

S. 694 shows plagioclase enclosed in augite, the augite often twinned. A pinacoidal cleavage is often developed in the augite.

S. 693 is of the same general type. The section is all ground to pieces.

S. 695 is also ground to pieces, but shows some well characterized leucoxene pseudomorphs after iron oxides.

S. 696 is one of the best sections for study. In it the augite is much fresher than in some of the others, and is often much twinned parallel to (100). A pseudo-diallagic parting parallel to the basal plane (001) is often developed. The extinctions of the feldspar vary from center to margin. Symmetrical extinctions near the center are 31°-33°[†] with 16°, Karlsbad twinning, and Baveno so superadded that the sections cannot be very far from perpendicular to the zone (010-001). Another double twin has 15°-12° with 32°. Another with 31°-29° seems to be also a double twin with the two albite twins of the other half of the Karlsbad twin having the same angles. Another has 37°-41° with 19°, another 36½°-41° with 21°, another 19°-39°, another 38°, etc. These indicate a somewhat more basic feldspar, but as a whole the angles point to the labradorite Ab_2An_3 as the variety of feldspar. Quartz occurs in the interstices.

S. 697 shows interstitial quartz, enstatite, diallage (?) and plagioclase.

The coarseness of grain in this rock is similar to that in the other diabases.

§ 5. Olivine diabase.

The next group that we make are close akin to the following group of quartz diabases. Yet they are not quartz diabases, and in the quartz diabases the olivine appears to me to be only accessory. Wichmann found no olivine.[*]

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[*] Geol. Sur. Wis., III, 627.

[†] Throughout this chapter angular measurements of extinctions connected with a dash are the extinction angles of feldspar lamellæ twinned according to the albite law When lamellæ twinned according to the Karlsbad law are also present they are joined by a bracket or the word "with."

Wadsworth found it abundant (Bull. Mus. Comp. Zool., July, 1880, VII, p. 70), G. H. Williams (U. S. G. S., Bull. 62, p. 197) seems to have found it abundant, and classes as an olivine diabase the Lighthouse Point dike, which from its accessibility and frequent description I take as the type of the quartz diabases. Olivine is certainly not at all rare in the quartz diabases but in quantity insignificant, probably irregularly disseminated and without any effect on the texture that I can see (Cf. Van Hise, U. S. G. S., Mon. XIX, p. 350). However, as just remarked, the two groups are in this region closely allied.

To the olivine diabases I assign the following thin sections:

Ss. 808, 828, 11860, from a two-foot dike striking across Presque Isle;

Ss. 11421, 11422, 11423, 11424, 11425, 11426, from South Island in Sec. 2, T. 48, R. 25;

Ss. 11489, 11490, from Middle Point, Sec. 3, T. 48, R. 25;

S. 11827, S. 12180, S. 12179, S. 9085.

See also dikes 61 and 175, described by Wadsworth (*loc. cit.* pp. 40 and 42).

In these sections even in the coarsest grained central rock there is but a trace of micropegmatite, instead of which (Ss. 11489, 11421, 11422, 11426) the texture is often ophitic,* i. e., the feldspar is embedded in patches of augite, between the limits of which corroded granules of decomposed olivine are crowded. At other times there are irregular smaller xenomorphic granules of augite wedged in between the feldspar. They are thus like the ophite melaphyres, Pumpelly's lustre-mottled rocks, which are so abundant in the Keweenawan.

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*It is to be noted that I use the term ophite, ophitic, as I have heretofore, i. e., in accordance with its original definition and in a narrower sense than it sometimes has been used.

Michel Lévy is responsible for the introduction of the term into petrography, and we take the definition from his "Structures et Classification des Roches Éruptives, p. 26: "Quand le dernier élément consolidé est un bisilicate (generalement pyroxénique), ses plages, sans contours extérieurs propres, sont lardées de cristaux plus anciens; ceux de feldspath notamment s'allongent suivant l'arête pg^1 (001) (010), ou s'aplatissent suivant g^1 (010), et l'ensemble prend une apparence caractéristique que j'ai décrite et déssinée dès 1877 sous le nomme de structure ophitique."

In this definition there are three points, first, that the pyroxene component is last consolidated, second, that it occurs in areas which are larded, as meat is larded for cooking, with streaks of older crystals, and thirdly that these crystals are much flattened or elongated. Vélain, for example, in his Conférences de Petrographie, p. 59, speaks of the ophitic texture as characterized by the elongation of the feldspathic element, and its distribution through the areas of the ferruginous element (pyroxene). But it has often happened that only the first or third point has been taken to be essential to the definition. Lapparent (Géologie, 1883, p. 630) alludes to the tendency of the feldspar to form elongate crystals as characteristic of the ophites, but his figures and descriptions show the areas of pyroxene in which they are embedded. We find that in their experiments on the reproduction of rocks, Fouqué and Lévy apply the term ophite, not to all rocks having elongate feldspar or xenomorphic pyroxene, but to those only that have the structure above described.

For the German use Rosenbusch (Mik. Phys. ii. 1887, p. 191; 1896, pp. 1114, 1009) distinctly includes the "large allotriomorphic augite individuals" as part of the meaning of the word, as is also apparent from his figure of the ophite structure (Plate ii, fig. 3, but not fig. 4, as will be seen by his description of plates), classing it as a variety of his intersertal, or diabasic structure. Among others who use the term in the narrower sense may be noted Rutley in "Granites and Greenstones", Harker in his Petrology, Judd in Q. J. G. S., 1885, p. 360, 361, 1886, p. 68, and Wadsworth, Minn. Geol. Sur. Bull. II, p. 107, while among those who use or define it in a broader sense are Zirkel, Kemp, Williams (in Standard Dictionary and Bull. 62, U. S. G. S.), and Loewinson-Lessing. But in its broader sense we have a couple of synonyms, diabasic, and intersertal, and when used in its narrower sense as applicable to that texture that produces the lustre-mottled effect, the etymology of ophite becomes strikingly appropriate. Plate VII, reminds one at a glance of the marking of many snakes. Of course, however, the determining factor is the usage of its distinguished sponsor.

The FELDSPAR seems more basic than in quartz diabases but is relatively larger than in effusives, except in the doleritic seams of the ophite. One section, S. 11860 = S. 828, contains porphyritic crystals of anorthite, with symmetrical extinctions greater than 45°, while symmetrical extinctions running up to 45° are not uncommon, so that the feldspar would be often classed in the bytownite or anorthite series, being over two-thirds anorthite. This applies to the most basic part only. Zonal extinctions occur as in the quartz diabases, if not quite so marked. Extinctions do not seem so high in marginal sections as in sections from near the center of the dike.

The patches of AUGITE are brownish, and show traces of pinacoidal cleavage, (S. 11827). They are very fresh.

OLIVINE is quite abundant. It is often highly idiomorphic, or in the corroded grains already mentioned. It is often heavily coated with iron oxides, and sometimes changed to chlorite and mica serpentine, or in S. 11860, apparently to talc.

The IRON OXIDES occur much as in quartz diabases. In the coarser grained forms (Ss. 11421, 11422) they occur in large angular, irregular or octahedral grains, which are distinctly moulded upon and hence of later origin than the feldspar. Accordingly they occur in the ophitic patches of augite, but not in the feldspar, the order of crystallization being olivine and anorthite, then magnetite, then augite. At the margins of the dikes there is a glass which tends to have a mottled appearance, and is heavily dusted with iron oxides, sometimes in growth-forms. (S. 828.)

No APATITE was distinctly recognized.

One yellow isotropic cube was visible in S. 11420, which may well be PEROVSKITE, but is possibly PICOTITE.

It will be seen that the rocks considered have a sufficiently distinctive character to be treated separately from quartz diabases. The tabulation below shows the variation of grain in one dike in sections taken at known distances from the margin, and also some observations of the extinction angles of the feldspars.

These observations on the grain are plotted in Fig. 17.

It is not merely accidental that the ophitic texture is associated in these olivine diabases with the more basic feldspar, greater amount of olivine, and generally more basic character. Fouqué and Lévy's experiments have shown that the ophitic texture is most easily formed in the more basic rocks and the same experiments show that the nearer anorthite a feldspar is, the higher the temperature at which it forms. Now the ophitic texture is dependent upon the feldspar being formed distinctly before the augite, so as to be enclosed in it. The occurrence of an ophitic texture is then a sign of a basic feldspar and the basicity of the feldspar is something of an indication of the basicity of the rock. The texture is not, however, solely dependent upon that. It requires also that the rock should be in a state of rest when this texture was formed, and that the rock should first cool through the temperature of

No. of specimen.	Distance from margin.	Character of feldspar.*	Diameter in millimeters of sections of—			
			Feldspar.	Augite.	Magnetite.	Olivine
11421	10 paces from N. E. side, i. e. 26 ft.	⎰ 22°-36° ⎱ 11° 28°-39° 45°-45° ⎰ 21°-49° ⎱ 17°-44° ⎰ 13° ⎱ 41°-40° ⎰ 20° ⎱ 35°-20° 46°-52° 37°-21°	1.56 x 0.125 1.34 0.156 2.03 0.156 Av. 1.64 0.146	4.06 5.94 Av. 5.0	0.28 0.21 0.81 0.62 0.53 0.62 Av. 0.58 x 0.46	
11422	10 paces from S. E. i. e. 26 ft.	28°-28° 11°-12° 35°-35° 33°-35°½	0.93 x 0.31 1.88 0.16 1.06 0.37 1.25 0.21 1.22 0.15 Av. 1.27 0.24	3.75 3.75 1.69 0.76 3.12 2.97 2.19 1.56 Av. 2.05	0.34 0.81 x 0.75 0.41 0.53 0.94 0.75 0.53 0.38 0.87 0.62	0.40
11426	5 ft. from S. E. contact.	25°-29° 27°-20° ⎰ 45°-45° ⎱ 15°	1.16 x 0.12 1.56 0.25 1.34 0.28	1.87 1.56 2.09	0.69 x 0.62 0.22 0.06 0.53 0.46	
11425	2 ft. from contact.	26°-25°; 31°-33° 35°-28°; 21°-18°	1.25 x 0.15 1.41 0.16 0.78 0.94	1.25 0.73 1.40	0.47 x 0.38 0.31 0.22 0.28 0.22	1.25
11424	near contact.	21°-22°	0.78 x 0.12 0.78 0.06 0.94 0.05	0.25 x 0.19 0.31 0.16 0.25 0.16	0.15 0.12 0.19	0.46
11423	N. E. contact.	28°-25° 18°-7°				
11420	Porphyritic. Total width about 18 paces or 47 feet.	50°-39° & 39° in a Baveno cross	0.38 x 0.06 0.62 0.06 0.87 0.13 smaller 0.32 to 0.37 x 0.03	0.12 x 0.12 0.06 0.09	0.02 to dust	0.25 0.19

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* Extinctions of lamellæ connected by the albite law are separated by a dash. Those connected by the Karlsbad law are grouped in brackets.

feldspar formation, and then pass fairly slowly through the temperatures of augite formation, i. e., the brighter red heats.

Hence the ophitic texture cannot date back of the period of final rest and requires that the rock shall be of a certain basicity, above but not too much above a bright red heat, at the beginning of solidification, and shall thereafter cool slowly and quietly. Hence it is that we do not find the ophitic texture at the margin, and (see below, § 6) in cases where the center of the dike grows markedly more acid the ophitic texture is confined to a zone at a certain distance from the margin.

Finally, as will be seen by reference to our descriptions of extrusive rocks, the ophitic texture seems to be more abundant in the flows than in the corresponding dikes. This may be due to the fact that when the rock had cooled down to red temperatures the absorbed gases had no considerable role to play in the flows, while in the dikes they helped to prolong the feldspar growth, making it more continuous and less sharply antecedent to the augite, and furnishing a magma in which both feldspar and augite formed.

It is obvious too from Pl. IV, that the time of augite formation would be longer if the initial temperatures of cooling were only just at or above the temperature of augite making, than if it were a little higher, and that may have something to do with it.

§ 6. Quartz diabase.

It must not be understood from the name applied to this group of rocks that quartz is a very prominent feature to the eye, for it is not. Only in comparison with other diabases is the quartz characteristic, for it is generally entirely microscopic. There are however a number of other characters, one or another of which is always present, that serve to distinguish rocks of this group very fairly, even to the naked eye. They have often been partly described.[*]

As a type we will take the great dike at Lighthouse Point, T. 48, R. 25, mentioned by Rominger,[†] Williams and Wadsworth. From various parts and outcrops of this dike the Survey has seventeen sections, and G. H. Williams had nine more which I have been kindly permitted to see, and several more, through Prof. Seaman and Mr. Sutton, from the collection of the Michigan College of Mines, so that we have a good chance to observe the range in its character, viz., coarse and fresh: Ss. 11763, 869, 871, 909, 934, 941, 947, 965, 8148, 11617 (W)*, 11622 (W), 11636 (W), 11666 (W); fresh, fine grained marginal forms, 966, 933, 875, 949, 962, 11762, 11621 (W), 13030; coarse but altered, 948, 910, 11672 (W), 11675 (W), 11615 (W); both altered and fine grained, 11616 (W), 11617 (W).

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[*] Williams, Bull. U. S. G. S., No. 62, 1890, p. 138; Wadsworth, Notes on the Geology of the Iron and Copper districts of Lake Superior, 1880, pp. 36, 37, report of State Geologist, 1891-92; Rominger, Geol. Sur. Mich., IV, Ch. VIII; V, Pt. I, p. 6; Bayley's description U. S. G. S., Mon. XXVIII, came to hand while this volume was going through the press. See the footnote at the end of § 9.

[†] Geol. Sur. Mich., IV, pp. 146-147.

Beginning in our study with the coarsest and freshest specimens, from the interior of the dike, not crushed nor weathered, we find a rock which to the naked eye appears fresh and glassy in lustre, neither silky nor as dull as are hornblende rocks. The color is dark gray, not greenish in tone, specked with white facets of feldspar, on which with a lens the twinning striations can be easily recognized, and the facets are elongate parallel to these striations. A negative character is the practical absence of that texture which from the appearance of flashing spots when the specimen is turned around in the sunlight has been called ophitic, lustre mottled, or poikilitic. (See pp. 48, 127.) This character is important in separating them from the olivine diabases and ophites. Under the microscope we see that the rock is made up of distinctly lath-shaped labradorite, of brownish augite and of opaque iron oxides. Accessory and embedded in the augite is often a little olivine, more or less altered, and there are always little interstitial spaces, which in the hand specimen appear as minute reddish specks, in and around which occur quartz, feldspar of the acid varieties, brown hornblende, mica, etc., as hereafter described. Neither olivine nor these "acid interstices," as we shall call them, appear to form any great part of the rock, but the latter are uniformly distributed and quite characteristic.

The LABRADORITE shows complex twins according to the albite law, which gives twin lamellæ with boundaries nearly parallel to (010), sometimes zigzag (S. 11828); combined with Karlsbad, pericline, Baveno and probably other laws.

The Karlsbad law combined with the albite produces three or four sets of lamellæ parallel to (010) with different extinction angles, and no position in which all the bands or lamellæ are equally illuminated. The pericline law produces lamellæ which in the zone of symmetrical albite extinctions are at right angles to the albite lamellæ. The Baveno law produces cruciform cross-sections and in general stellate groupings, since the feldspar is developed in tablets parallel to (010). The extinctions can be symmetrical for the albite lamellæ in both parts of a Baveno twin only for a particular section, such as was encountered in S. 11484. The extinction is dispersed, so that between cross-nicols a distinct change from bluish to brownish is noticeable on passing through the position of greatest darkness. Careful study of a section almost perpendicular to the positive bissectrix in S. 11801 led to the diagram, fig. 27, illustrating the approximate position of the optical constants, which agrees very well with Lévy's diagram for Ab_3An_4 in the "Détermination des Feldspaths." (See also S. 909.) The dispersion of the extinction is easily noted in the bluish tinge outside and brownish tinge inside, of the dark zone of the feldspar in case it is turned so that the center is beginning to get light while the margin is not yet dark. It also varies from center to margin in such a way as to indicate a decreasing percentage of lime toward the margin, and the margin is often continued out into pegmatitic intergrowth with quartz. In such case its relative refraction (see below, § 9) shows that it is orthoclase or albite. Twinned crystals cut nearly perpendicular to the lateral pinacoid (010) show nearly symmetrical extinction angles, generally between 20° and 30°. The extinctions tabulated below* show that, e. g. in S. 941, the centers of the feldspars must be in composition between Ab_1An_1 and Ab_2An_3, which agrees with the analyses made for Van Hise.

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* (W) affixed to a number denotes that the section and number are of the Williams collection.

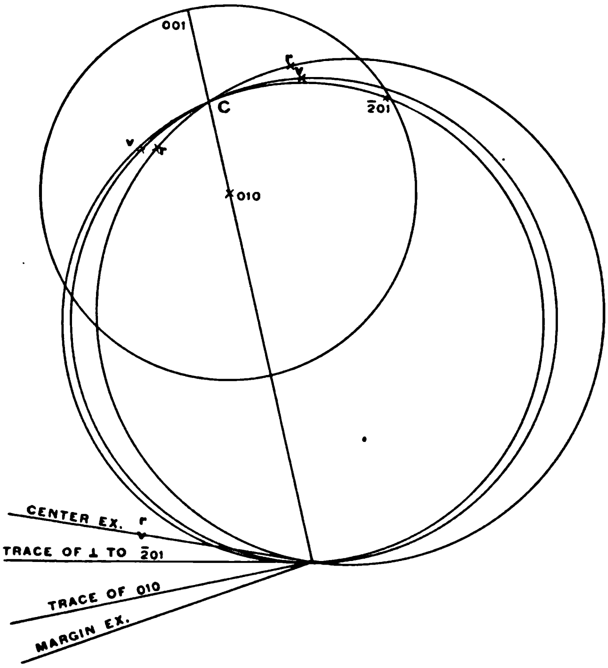

FIG. 27

Stereographic projection (see p. 40) upon the lateral pinacoid, i. e., m (010), of labradorite, showing the positions and dispersion of the optical axes.

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* As before, Albite connected by -, Karlsbad by brackets.

T. 48, R. 25		Averages			
11484	24°-18°		11878	30°-37°	33°
Margin	14°-20°		769	15°-23°	
	19°-23-				
	27°-20°			26°-24°	
Baveno twins, angle between arms of cross 83°	22°-22° 21°-19°			20°-30°	
				26°-32° 0°	
		21°			22°
11485	22°-24°		11763	23°-24°	24°
Center	20°-12°				
	42°-34°		869	32°-30°	31°
	25°-31°				
	20°-21°		941	38°-32° 11°-11°	
		25°			
11735	31°-32° 13°			12°-12° 38°	
Margin	24°-23°				
	29°-30° 13°		875	17°-17°	
				37°-35°	
	28°-35°	26°		37°-35°	
					26°
11750	28°-24°				
Center	26°-31° 16°		949	30°-32°	31°
	27°-31°				
	18°-19°				
	25°-31°				
		25°			
11801	up to 30°				
11807	25°-28°				
Margin	26°-25°				
	23°-23°				
	23°-27°				
	24°-30°				
	19°-22°				
	26°-26°				
		24°			
763	up to 30°				
767	not up to 30°				

Comparing the extinctions with those observed by Irving in the "Copper-Bearing Rocks"* we see that they are nearest to the extinctions of the feldspars in his olivinitic and lustre mottled rocks. Enclosures of glass, iron oxides, etc., in the feldspars are more common in the marginal forms.

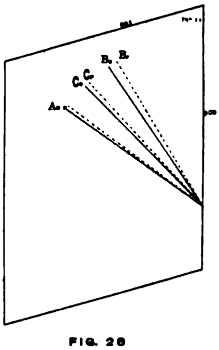

FIG. 28

Projection on m (010) of the optical axes of augite.

The AUGITE is in thin section very light pinkish brown, parallel to (100), lighter and more yellow perpendicular to it. The optical angle is small, the dispersion r> v is stronger for the axis which is more nearly parallel to the prism axis as shown in Fig. 28 (S. 13749). The pinacoidal cleavages are subordinate to the prismatic, but there is often a twinning on the front pinacoid and sometimes a basal twin striation or twin lamellation is visible (S. 844). The augite is not commonly idiomorphic, but may be so against the acid interstices (S. 909), then showing the forms of an octagonal prism with the pinacoids more developed than the prisms (S. 778). Sometimes it is surrounded by a border of brown hornblende. Occasionally the augite has an odd rounded growth, which suggests at once the origin of the hornblende crystal described and figured by Williams.*

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* U. S. G. S., Mon. V, Chap. III.

A series of augite crystals seem to have started growing outward from a center in various directions, all having the clinopinacoid (010) parallel. The lines between them are irregular, and no definite twinning law can be made out, though they remind one of the "knäuel-artige Verwachsungen" mentioned by Rosenbusch.† The angle between the vertical axes of successive parts seems to be very small.

The OLIVINE is distinguished from the augite by its more nearly colorless, or its greenish hue, and greater decomposition especially along the cracks which are largely pinacoidal. In favorable cases it can be determined that the optical angle is larger than that of augite. In form the olivine is either rounded or terminates with angles not far from 90° (82°). (Fig. 29.) Even when the grains of olivine show no crystal form, their outlines are not determined by other minerals, i. e., xenomorphic, but rather suggest corroded fragments which are commonly embedded in the augite, rather than the feldspar. They are most sharply idiomorphic near the margin.

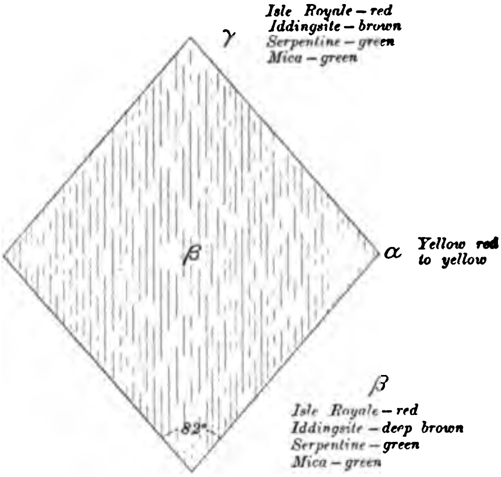

FIG. 29

Illustrates the comparative pleochroism of micaceous alteration products of olivine.

The grains of iron oxide in reflected light show sometimes a bluish lustre, when we call them MAGNETITE; sometimes a dead black lustre, when we call them ILMENITE. The ilmenite has been observed surrounding a magnetite centre (S. 947), or traversing it in streaks (S. 965). The iron oxide grains are often irregular, and not idiomorphic against the feldspar, but occur sometimes also in octahedral forms, especially in those skeletal forms which are due to rapid growth, as in S. 11763—near the margin.

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* U. S. G. S., Bull. 62, p. 183, fig. 28. Compare Lawson's polysomatic augites.

† Mik. Phys., I, 1892, p. 513, and Pl. XVIII, fig. 5.

More or less abundant are the ACID INTERSTICES (Pl. XVI), against which the feldspar is generally, the augite and magnetite often, idiomorphic, although the augite is often bordered with brown hornblende (S. 869).

BROWN MICA also occurs associated with the iron oxides, often having its basal plane applied to the face of the iron oxides, and so occurring with them as to indicate a genetic connection.[*]

The BROWN HORNBLENDE just mentioned is not the same as the ordinary green uralite by any means, in fact may be also turned green at the same time that the augite is uralitized. Yet it interdigitates with, and runs into, the augite in a way that shows plainly that it is derived from it. It has also been noted by Irving and Van Hise.

From the feldspar laths growths of micropegmatite often spring out, the feldspar of which is continuous with the acid margins of the feldspar. There are also in these interstices independent grains of quartz? They are traversed by long apatite needles, hexagonal and idiomorphic. They are rarely if ever so fresh as not to be clouded over with a reddish ferruginous dust, and not to contain small folia of brown and green mica (S. 965).

The micropegmatite growths are illustrated in Pl. XVI from S. 7931, one of the diabase granophyrite group.

A proper understanding of these interstices, which appear to be the same mentioned by Rosenbusch, Mik. Phys. II, p. 194, ed. of 1887; 3d ed., 1896, pp. 1117, 1140, 1143–1146, 1149, 1307, and of their origin seems important yet difficult. Wadsworth[†] and Irving[‡] take micropegmatite to be a secondary texture, replacing feldspar, etc., and Williams[§] seems to consider this interpretation possible. Says Wadsworth, speaking of some Minnesota rocks:

"In the earlier stages of alteration of the groundmass or feldspar there arises a confused mass of viridite, ferrite, magnetite, quartz grains, feldspathic material, etc. As this alteration progresses the tendency is to assume a radiated fibrous structure or else an imperfect graphic form. Further changes in the rock results in the quartz taking upon itself a true graphic form, the same as that seen in graphic granite, while in still further changes the quartz is in rounded or irregular forms in the midst of the altered reddish-brown feldspathic material. The pyroxenic element in the meanwhile has been altered to biotite and hornblende;—"

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[*] Kemp, Bull. Geol. Soc. Am., V, 1893, p. 220; Williams, *loc. cit.*, pp. 139, 140; Wadsworth, Minn. Geol. Sur., Bull. II, pp. 64, 65, and farther references given there; Cf. also C. H. Smyth, on biotite and magnetite reaction rims, Trans. N. Y. Acad. Sci. (May 21, 1894) XIII, p. 213.

[†] Minn. Geol. Sur., Bull. II, pp. 67, 68, 81, 103, 109.

[‡] Copper-Bearing Rocks of Lake Superior, U. S. G. S., Mon. V, 1883, plates v, xii, xiv, xv, descriptive text.

[§] U. S. G. S., Bull. 62., p. 141.

In this view of micropegmatite in which Wadsworth was at first almost or quite alone, he has been finding more and more followers,[*] and as my own observations do not agree with them, but rather with Rosenbusch, but point to other, theoretically and practically very interesting conclusions, I will give them very fully.

In this discussion, in order to have a broader basis to eliminate subjective statements, and put results in numerical form, we will not confine ourselves to the Lighthouse Point dike, which is nevertheless a very good example, nor to the quartz diabase group, but include all the specimens of diabasic dikes more recent than the greenstone schists, from townships 48 and 47, ranges 25 and 26. We will also include the sections from the same region described by Williams. There are also some described by H. B. Patton. In all we have some 245 specimens to study, including some altered porphyrites and uralite diabases which may in part represent weathered forms of this group, but I feel sure also represent other distinct igneous formations, yet not including rocks so far changed as to rank with hornblende schists.[†]

In the first place these micropegmatite growths do not generally seem to replace the feldspar, iron oxides or augite. Each of these is at times idiomorphic against them. The occurrence of reddish pigment and folia of green mica suggests that glass has been replaced. They do not occur, however, at the glassy margins of dikes, and when decomposed glass occurs there it has a very different appearance and I have not seen any transitions between glass or decomposed glass and micropegmatite. In fact the most convincing sign of the nature of the micropegmatite lies in the fact that it has mutually exclusive relations with textures that are undoubtedly primary and sometimes occur in other parts of the same dike. The poikilitic or ophitic texture occurs seven times in the fresh non-uralitic specimens. In no case is micropegmatite mentioned as associated. In uralitic diabases or porphyrites a poikilitic texture is mentioned nine times, but only in one case is quartz, which is distinctly said to be secondary, mentioned as occurring with it,—in no case micropegmatite. Grouping together specimens distinctly mentioned as marginal in the field notes with those which by their glass,—fresh or altered,—porphyritic and microlitic texture or characteristic iron oxide growths betray themselves as originally glassy marginal rocks, we find 57 of them. In 32 the augite is quite fresh, and in only one is micropegmatite said also to exist. This—S. 11750—proves on revision to be one in which a little decomposed glass was suspected to exist in the mesostasis while in other parts the interstices were granophyric, and is no real exception. In 9 of the uralitic or chloritic ones (9 out of 24) quartz is mentioned as occurring, but not once micropegmatite. The quartz is often distinctly stated to be secondary, not interstitial at all, and in other cases the existence of the altered glass is dubious, but that my observations might be surely impartial I have not revised them with this question in mind. The micropegmatite being, therefore. thus mutually exclusive with glass and poikilitic texture must be itself a primary texture or replace one.

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[*] Cf. Bayley in U. S. G. S., Mon. XXVIII, p. 520, and foot note at the end of § 9.

[†] I do not include in my statistics the sections from Bayley and the Michigan College of Mines, as they were selected to show the micropegmatite and have not the same objectivity.

Now as to its relations to uralitic and chloritic changes, we find micropegmatite in 13 out of 62 fresh basic dike rocks (20%); in 18 out of 149 uralitic ones (12%); in 3 out of 41 chloritic ones (8%).

The percentage of rocks observed to contain micropegmatite decreases with their alteration, and this indicates clearly that it is the result of some process different from the change to uralite or chlorite. If, as we properly ought, we subtract from these figures the number of sections which have textures exclusive of micropegmatite, the results would become still more striking, for in fact *all the fresh, neither ophitic nor marginal, sections are recorded to contain micropegmatite,* except—

S. 11490, which is from a dike elsewhere ophitic, and tends itself to be porphyritic,

S. 11708 (W) a small dike (Williams does not mention glass, but my sections from the same dike show it),

S. 11485, not altogether fresh,

S. 845, which is only two feet from the edge of a dike that elsewhere has micropegmatite,

And a number of Williams's sections, e. g., from the Lighthouse Point dike, in which he says, however, that primary quartz does at times occur, viz.: 11617 (W), 11622 (W), 11636 (W), 11666 (W) and 11814 (W).

Finally we have S. 11811, from an east and west diabase dike about 30 feet wide, near Dead River, 1180 paces N., 1250 paces W., Sec. 10, T. 48 N., R. 25 W., in which instead of acid interstices we have a mesostasis full of sheaves of feldspar microlites as described in Rosenbusch.[*] This is, therefore, the one real and decided exception to the rule that the central parts of large basic dikes which are not ophitic contain micropegmatite. But if micropegmatite occurs in practically all the fresh central non-ophitic specimens, it occurs in but about 16 out of 78 of the central, non-ophitic, but uralitic specimens of the diabases, and in 3 out of 16 chloritic ones. This I believe to be due to its obliteration in the processes of uralitization, weathering or crushing, but it may also be conceived to have originally occurred more in the youngest set of dikes. If, moreover, the micropegmatite were due to mere weathering, the absence of micropegmatite in the Keweenawan flows of similar character would be unaccountable.

The extension of these numerical comparisons to all the dikes collected in the Upper Peninsula would only strengthen our results. The role of apatite is well indicated by the fact that out of 52 times that it is noted it is 8 times in association with the fresh micropegmatite, 10 times with uralite and pegmatite, once only in an ophitic rock, 4 times only in glassy forms, and the remaining times is most often in dikes which elsewhere contain micropegmatite, or have the acid interstices plainly indicated by quartz, brown hornblende and mica, etc. It cannot be said that micropegmatite is an absolutely necessary feature of these interstices. It is merely the most unequivocal feature. The way the needles of apatite grow across these cavities does not suggest to my mind their origin from decomposed glass,[†] but suggests rather the apatite found in drusy or miarolitic cavities like those in the basalt of Capo di Bove.[‡] In 13 out of 31 of the sections of the Lighthouse Point dike is apatite mentioned, but in not one of the marginal sections. In a number of other dikes the same thing is true. Ss. 757, 996, 997, 991, have it, Ss. 756, 994, 761, not, the latter three being marginal, and all the sections being from the same dike. This concentration in the center of the dike does not seem natural for a secondary origin.

If, then, these cavities were during the formation of the rock, at the close of the augite formation, filled neither with any of the previously formed minerals nor glass, they may have been filled with the residuum of the molten magma. Enough of the rock was formed to make it perfectly solid, for no farther motion could take place without disturbing the micropegmatite borders of the feldspar laths and fracturing the excessively delicate apatite needles. The remaining interstices seem, agreeing with the general law of increasing acidity in residual magmas, to have been filled with the final concentration of an acid aqueo-igneous magma which had been corroding the olivine and forming the less basic augite from it. In this magma were also concentrated the absorbed gases, aqueous and otherwise, which the dike margin originally contained and which, as the dike solidified at the margin, would probably be driven from it and concentrated at the center.

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[*] Mik. Phys., II, 1896, p. 1117.

[†] Wadsworth, Minn. Geol. Sur., Bull. II, p. 68.

[‡] See also Dana's Mineralogy: also Vogt, Neues Jahr-Buch für Min., (1894) i, p. 96, describes similar apatite needles in the cavities of slag.

The acid magma thus left seems to have proceeded to produce brown hornblende upon and out of the augite, brown mica upon and out of the iron oxides, as Smyth has suggested, and pegmatite growths on or out of the feldspar,* while apatite needles formed across the cavities. This explanation of these cavities accounts well (1) for their occurrence only at the center of dikes, (2) for the fact that the minerals formed and structures are those of more acid rocks, which we see in their obvious parallelism with the rocks more rich in micropegmatite, such as the diabase granophyrite, Ss. 11727 and 11831 (W).† The occurrence of quartz feldspar micropegmatite intergrowths is described by Rosenbusch within miarolitic spaces,‡ although in a private letter to Patton he expressed himself as not inclined to consider these granophyric growths as similar. Nor do I conceive that they were in cavities left after the consolidation of the whole rock magma, filled in by infiltrating foreign substance, though if they are truly secondary products, such cavities may have guided their deposit, but rather the refuge of that part of the magma that the loss of heat due to injection did not solidify. Thereafter the hot aqueous solution would, as we have said, react on minerals already formed, and would form crystals much more slowly, perhaps not until the solutions had been affected by percolation. They correspond thus to Brögger's§ second phase in the formation of his pegmatite dikes. The brown hornblende may be akin to barkevikite. Brown hornblende generally contains potash,¶ as we see from its abundance in alkaline rocks. It seems not impossible that the so called reaction rims around olivine and other minerals* may also be produced with the co-operation of residual magma. The minerals produced are often such as might be expected from such action, and like those we have in the acid interstices. It must not be forgotten that a theory of the origin of these interstices must account for the chemical character of the minerals formed in and about them, for the potash and for the chlorine and fluorine of the apatite and brown mica. Moreover, it is *a priori* almost necessary to believe that in rocks consolidating under such circumstances as to prevent the escape of aqueous or other gases there will be a residuum which cooling will have only a slight tendency to solidify. The fact that these interstices seem at times to be centers of decomposition is in full harmony with a conception of them as microdrusic.

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* See foot note at end of § 9.

† Williams, *loc. cit.*, pp. 181, 182; Rosenbusch, Mik. Phys., 1896, II, p. 226; Patton in Ann. Rep. State Geol. Mich., 1891-92, p. 185.

‡ Mik. Phys., 1896, II, pp. 55, 67.

§ Groth's Zeitschrift für Kryst. 1890, XVI, p. 162.

¶ Cf. Dana's Mineralogy, 1892, pp. 396 and 403; Williams, Am. J. Sci. (May, 1890) XXXIX, p. 352.

Precisely the same phenomena as those we have been describing have been observed by Lawson about Rainy Lake,† the pegmatite and quartz being confined to the center of the dikes and associated with apatite. Analyses show that the silica and alkalies distinctly increase towards the center ‡ As may be inferred from what we have said, these dikes with acid interstices have well-defined fine grained, glassy and porphyritic walls. Ophitic augite rarely occurs in the same dike with micropegmatite, although it seems, comparing Lawson's description of S. II from the Stop Island dike with S. 11615 (W) from the Lighthouse Point dike, and S. 997 from the Brook sections, as though in some cases, between the glassy margin and the center with acid interstices, a zone occurs from 4 to 10 feet from the contact, where there are traces of ophitic texture.

In the marginal sections from these dikes (Ss. 566, 949, 875, 933, 962, 11762, 11616 (W) of the Lighthouse Point dike) the LABRADORITE, remaining essentially the same in character of extinction angles, etc., becomes much more variable in size, being as it were porphyritic, yet without any sharp line between the larger and smaller laths. Enclosures of glass and iron oxides, marginal or arranged parallel to (010), become much better developed than in the coarser grained rocks. These enclosures are sometimes tubular. The way in which the enclosures parallel to the lateral pinacoid are formed is well illustrated by cases in which the feldspar runs out into split and forked laths characteristic of rapid cooling (S. 11751). It often gathers into stellate radiate groups, in making which the Baveno cruciform twins are prominent (S. 11484). The already mentioned occurrence of younger sheaves of andesite feldspar in the interstices of the ordinary intersertal, i. e., diabasic or tholeyitic, texture, is rare (Ss. 11811, 11807).

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* See Kemp Bull. Geol. Soc. Am., 1893, V, p. 218, etc., also H. B. Patton in Ann. Report, State Geol. Mich., 1891-92, p. 19.

† Proc. Am. A. A. S. xxxviii, 1889, p. 246; Am. Geol., VII, 1891, p. 153.

‡ Compare the table of analyses at the end of § 11.

The AUGITE also tends to occur in the spherulitic groups already described. When finer grained, it also occurs in rounded or idiomorphic granules which do not fit closely to the feldspar. The olivine is in sharp idiomorphic forms (Cf. Fig. 23 and S. 11751), i. e. k (021) and b (010), and the cleavage face (100). It is generally bordered with granules of iron oxides, probably due to incipient alteration, or possibly magmatic absorption.

The iron oxides of the ground mass, MAGNETITE, are in those club shaped forms of growth that commonly occur where there is a little glass left, and are figured and described by Geikie* as characteristic of margins of dolerite. It is true in our rocks also that such forms are characteristically marginal. In S. 914 occur some brownish translucent branching forms, apparently ilmenite. In S. 11878 is a deep brown glass with eutaxitic growth forms.

The distribution of these rocks which contain the acid interstices confirms our conception of their character. They are characteristically dike rocks and occur in all the formations up into the Upper Huronian, being scattered through the great band of greywackes and slates that run south from L'Anse, and in fact everywhere except in the Keweenaw and younger formations. Now why are rocks of this type absent in the Keweenaw formation? Micropegmatite occurs only in pebbles in conglomerates. From Isle Royale we have, as we have shown, a continuous section of some 9,000 feet, represented by over 1,000 thin sections showing rocks of very similar, we may say almost identical chemical composition (compare the analyses of rocks in chapter IX with those of the end of this chapter), of various degrees of coarseness, and in all stages of surface decomposition. The acid interstices cannot therefore be wholly dependent on chemical character or coarseness, for we find all degrees of basicity of feldspar associated with great range in coarseness and freshness among the Keweenawan rocks, nor on the secondary alterations such as have affected the Keweenawan rocks, nor, as we have seen, on the dynamometamorphic alterations which have produced the amphibolites. We seem driven to the conclusion to which we came from internal evidence,—that the acid interstices are essentially dependent upon some condition characteristic of an intrusive mass. It may be a secondary alteration perhaps, *if of a kind which does not occur in flows.* Solution of a siliceous country rock, or intermixture with an acid magma as described by Winge and Moberg[*] will hardly cover the case of a whole family of dikes, though it may be noticed that the kind of effect produced by solution of quartzite and granite by a basic magma would be expected to be analogous to that produced by an acid residual magma. This being granted, the difference in structure and grain are no argument against the conclusion supported by stratigraphic relations, that the quartz diabases are coeval with some of the Keweenawan traps, and are really their intrusive equivalents.[†] The orthoclase gabbro and diabases of Irving have points of similarity with this group, but much less acid feldspar.

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*Trans. Roy. Soc. Edin. xxix, Pl. xii, fig. 12, and p. 497. Cf. Rosenbusch, Mik. Phys., I, 1892, Pl. II, fig. 5, and II, 1896, p. 1012.

We find indeed in the Keweenawan effusive rocks of similarly coarse grain interstices corresponding to the acid interstices, but filled with delessite, calcite like that which Törnebohm described as primary, chalcedony, etc. The formation and filling of these cavities may be explained as follows: The lava flow solidified first near the surface, and the basic feldspar forming (as in Fouqué and Lévy's experiments) before the augite, made a sort of trellis-work through the whole mass, which is thus rigid. Then the augite, the last to form, when it contracted in crystallizing, left interstices not in this case filled with residual magma, but with gas, giving the rock a porous yet not amygdaloidal texture, as these cavities do not have rounded walls.

They are of course filled at the first approach to alteration, generally first with a coating of delessite, whose fibers are at right angles to the walls of the cavities. They may be filled in by percolation in various ways Such an effusive texture is illustrated in Pl. VI, fig. 3, while the acid interstices are shown in Pl. XVI.

In prosecuting these investigations it was of course important to follow one dike from margin to center, just as Lawson had done,[‡] and the results of this study on the grain of the Lighthouse Point dike and one other, are given in the table below. This table contains, beside the data as to grain, measurements of the extinctions of the feldspar, and also, for comparison, similar data from Lawson's paper, from Fouqué and Lévy's work on artificial rocks and from one of the large Keweenaw flows. In Chapter V more data will be found and Figs. 17 and 15 give graphic representations.

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[*] Rosenbusch. Mik. Phys., II, 1896, p. 1304, 1307; compare also Bayley U. S. G. S., Bull. 109, pp. 109-111, and Harker on the Carrock Fell gabbro, Q. J. G. S., 51, 1895, p. 125.

[†] All the similar rocks described by Rosenbusch, II, 1896, pp. 958, 1144-47, are also intrusive.

[‡] Am. Geol., VII, 1891, p. 153.

The curves of grain of Fig. 17 indicate, e. g., for the dike of Sp. 11426 (see § 5) a central zone of uniform grain for augite about 2-3 the total breadth; for the dike of Sp. 13749 a central zone of uniform grain for augite about 60% of the total breadth, and Lawson's statements are in harmony, indicating a similar zone less than 80%. If now we use Pl. IV to find to what elevation the curve numbered 8, which represents the temperature 2-3 the way from center to margin, continues to have practically the same slope as curves for points nearer the center, we find it is somewhat above 30, the initial temperature being 78.5.

Thus if we assume the constant temperature of the margin of the dike to have been 100° C. and the temperature of solidification and augite formation, after Barus (U. S. G. S., Bull. 103, p. 54) to be between 1095° C. and 1170° C., we shall have for the initial temperature of the dike, $(78.5 \div 30) \times (1170 - 100) + 100 = 2900°$ C. as a maximum, while if we assume, owing to the presence of water, a lower temperature of formation for augite, it would not be difficult to suppose as low an initial temperature as 1500° C.

Explanation of table:

In the first column is the number of the section, in the next six columns are notes on the composition, viz., in the second column the presence of micropegmatite noted by p, of quartz by q; in the third column the presence of biotite by b; in the fourth, the presence of brown hornblende by h, or of uralite by u; in the fifth, the presence of apatite by a; in the sixth, the presence of glass by g; in the seventh, the presence of eutaxitic growths of iron oxide by e; in the eighth, distance from the margin; in the ninth, characteristic feldspar extinction angles and miscellaneous notes; in the tenth, average length of feldspar laths, in millimeters; in the eleventh, average breadth of same; in the remaining columns, average linear dimensions of augite, magnetite and olivine, respectively, all the dimensions being determined in the case of my observations by measuring the dimensions of the largest individual in three different fields of view.

Lighthouse Point dike. Fresh, coarse, central type.								To this group belong 11617 (W), 11622, 11636, 11666.	Average dimensions of constituents in mm.					
No. of specimen.	Micropegmatite, resp. quartz.	Biotite.	Brown hornblende, resp. uralite.	Apatite.	Glass.	Eutaxitic iron oxide.	Distance from margin.	Feldspar extinction angles, etc.	Feldspar.		Augite.	Magnetite.	Olivine.	
									1.65 x 0.34		1.29	0.7	....	Average of measurements for groups below.
869	p	b	h	a	....		12 ft.?	32°-30°	1.8	0.5	1.8	1.1	....	869
11763	p	b	......	a	....		?	23°-24°	1.6	0.4	1.3	0.9	0.5	11763
909	p	b	h	a	....		24 ft.		1.3	0.3	1.3	0.7	0.5	909
871	?p	....	......	a	....		12		1.8	0.5	0 9	0.6	0.5	871
947	p	....	......	a	....		30		1.8	0.4	1.1	0.5	....	947
965	?	b	......	a	....		39		1.7	0.3	1.4	0.5	0.6	965
934	p	....	......		....		23	38° 32° { 38°	1.5	0.3	1.0	0.5	....	934
941	p	....	......		....		24	11° 11° } 12°-12°, i. e. ab 60% An	1.7	0.3	1 0	0.6	....	941
Fresh; intermediate in grain. Compare 11708 (W) from another dike.														
									1.2	0.25	0.35	0.16	....	Average.
8148	?	b	h	a	....	....	....		1.2	0.3	0.6	0.3	....	8148
906	?	....	....	....	....	....	3 in.		1.2	0.2	0.1	0.3	....	906
Fresh; marginal. Compare 11719 (W) from another dike, also 11621 (W).														
									0.8	0.14	0.10	0.03	....	Average.
875					g	e	....	17°-17° 37°-35°, 24°-28°	0.8	0.16	0.40	0.1	....	875
933							....		0.8	0.16	0.16	0.02	0.2	933
949					g	e	....	30° 32°	0 66	0.2	0.16	....	....	949
962					g	e	....		0.75	0.1	0 06	0.02	....	962
11762					g	e	....		0.9	0.11	0.06	dust	0.2	11762
Thin section shows contact.														
13030	....	....	....	?	.	..	....		0 5	0.11	dust	dust	0.15	13030
Coarse; more or less altered. Compare 11675, 11672, 11615 (W). Williams gives the average dimensions of the feldspars as								from..	1.5	0.25				
								to.....	1.	0.15				

Quartz diabase dike from cut on Iron Range and Huron Bay R. R.; 1500 paces N., 50 paces W. of the S. E. corner of S. 35, T. 50, R. 31.

13749								20 ft.		1.9	0.8	1.5	1.00		13749
13748								8		1.7	0.5	0 8	0.80		13748
13747								21		1.2	0.2	0.7	0.40		17747
13746								0.5		1.0	0.16	0.2	0.06	0.3	13746
13745								0.0		1.2	0.16	0.1	0.002		13745

Lawson's Stop Island dike, Am. Geol. 1871, VII. pp. 153-164.

IV	q		h	a				75	Analyses at end of chapter. Size of quartz 0.84.	2.00		1.00	0.70		IV
III	q							15	Size of quartz 0.056.	0.35	0.10	2.00	0.70		III
II			h					4		0.56	0.056	0.84	0.126		II
I								0		0.052	0.004	0.03	0.0147		1

Artificial rocks of Fouqué and Léry. (Synthése des Min., etc., 1882, pp. 48, 60-75.)	Feldspar.		Augite.		Magnetite.	Olivine.
Andesite: composed of 4 parts oligoclase, 1 part augite, kept 3 days at heat 3, i. e. low white heat (steel softens, copper melts, about fusion temperature of labradorite), gives	0.25 x	0.015	0.06 x	0.02		
Labradorite porphyrite: 3 parts labradorite, 1 part augite, kept 3 days at heat 3	0.25	0.025	0.05	0.025	0.01	
Basalt and melaphyre: 6 parts labradorite, 2 parts augite, 6 parts olivine: 48 hours at heat 2 (steel melts), cooled, then 48 at heat 4 (cherry red): porphyritic	0.15	0.03	0.05	0.015	0.005	
Ophites (a): 1 part anorthite, 2 parts augite, 4 days at heat 2, 3, days each at 3 and 4						
(b) 1 part anorthite, 1 part augite, 4 days at heat 2, 3 days each at 3 and 4, ophitic	0.4		0.75	0.04	0.015	
(c) 1 part labradorite, 1 part augite, only partly ophitic						

The Greenstone.

No. of section.	feet from bottom of flow.	Extinction angles of the feldspar.	Feldspar.		Augite.	Magnetite.	Olivine.
15252	119	38° 23° 7° 2° 41° 37° 34° 24° 31° 23° 39° 34° 19°-19½° 30° 28°	0.56	0.094	9 to 6	0.15	0.25
15253	95	14° 14°; 28°-30°; 24°-36°; 35° 37°; big phenocryst 43°-43°	0.46	0.13	7 ±	0.024	0.28
15254	73	9° 4° 25° 27°	0.30	0.07	5	0.11	0.33
15255	52	20° 23½°	0.39	0.06	4+		0.30
15256	24		0.38	0.04	2 9	0.12	0.17
15257	1		0.19	0.03	1.25	0.08	
15258?	0		0.27	0.04			

From these tables we see: (1) That the feldspar is very much coarser in proportion to the other ingredients, in the dike than in the much thicker flow, increasing in size toward the center, but increasing more rapidly in breadth than in length. (2) In both dikes and flows the augite and magnetite are but dust or very fine granules at the margin where solidification took place immediately after intrusion, while the olivine and the feldspar even at the very margin have a notable size and evidently began to form before the final arrival of the rock at its place of rest. This is expressed in diagrams by the fact that the curves of size for augite and magnetite begin at the margin at the origin of coördinates, while the others do not. The margin of a dike and the underside of a thick flow have just the same microlitic and porphyritic texture, and in both the feldspar has a porphyritic appearance, since beside the feldspar microlites that had begun to form before cessation of motion, there are smaller forked or skeletal feldspar microlites produced in the act of solidification. As we pass from the margin, however, the distinction of the two generations fades entirely away. In reality there never were two distinct periods of feldspar formation, but as the feldspar was forming, the chill from the contact intervened so as to suddenly wind up the process with a whole crop of little crystals. Toward the center the process continued with no intermission, and no marked break, as the change in the rate of cooling was less marked. (3) The grain of the augite is more uniform in the central part for the dikes than for the effusive. This indicates, as above said, that they were injected at a temperature considerably above that of the formation of augite. Suggestions that similar facts are generally true, i. e., the central part of the dike uniform in grain, and the margin for a narrow zone decreasing to aphanitic texture, occur in other authors.*

I wish to emphasize the fact that the feldspar began forming before the augite or magnetite, because in spite of the clear evidence of experiment contrary statements are often encountered. In the dike the formation of the feldspar seems to have continued without sharp interruption throughout the formation of the rock (though, as shown by the gradually changing extinction angles, it contains a gradually increasing percentage of Na_2O) and thus overlaps the formation of the augite at both ends. In the flow, on the other hand, the formation of the feldspar was sooner stopped and it is sharply automorphic.

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*Lawson, Am. Geol., VII, 1891, p. 154; Bull. Denison University, II, 1887, 2, p. 134.

§ 7. Alteration forms of quartz diabase.

(a) Atmospheric. As we have said, the direct action of the atmosphere produces a narrow brown zone in which the augite weathers to iron hydrates and from the surface of which the diabasic arrangement of the feldspars and the granules of the magnetite project.

Another form of alteration, somewhat deeper seated, has been very carefully studied by Mr. Patton, and is given in the following descriptions. I will only add that this alteration is described by Van Hise * and by Rominger †, and has been already briefly referred to by Patton in the 1892 report, etc.

(b) Kaolitic alteration of diabase. (H. B Patton.)

S. 13456.

Diabase.

Cleveland Mine, Lake Shaft. Sec. 20, T. 47, R. 27.

Hand specimen. Rather fine grained; massive; dark gray; but weathers brownish. Fracture uneven.

U. M. Under the microscope the two principal ingredients, plagioclase and augite, are about equally abundant. The former is quite fresh, has well formed lath shape, and shows frequently a symmetrical extinction angle of about 30°; it is, therefore, labradorite.

The augite shows rarely crystal faces. Its color is reddish yellow. It is not as fresh as the labradorite, but contains more or less unrecognizable clouded substance of a greenish color.

Accessory; iron ore abundant as usual, and a little apatite.

A few small patches of vivid, dark green color, occur. These appear to be scaly in structure and to have not very high double refraction.

A chemical analysis of this rock made by Mr. Fred F. Sharpless is given at the end of the chapter.

S. 13457.

Chlorite schist. (Patton.) Cleveland Mine, Lake Shaft. Sec. 20, T. 47, R. 27.

Dike, cutting ore.

H. Sp. Has a crushed, schistose appearance: color dark gray, stained red with iron oxide on the surface. Feels greasy and has earthy smell.

U. M. Consists principally of a crushed, schistose, dark green, chloritic mass, throughout which are thickly scattered dark red hematite scales and powder.

Numerous colorless or light green patches are composed of minutely crushed feldspar, or probably of quartz. That some of this is feldspar is indicated by an occasional grain large enough to give a biaxial image in convergent polarized light.

This rock is very likely an altered diabase.

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* U. S. G. S., Mon. XIX, pp. 357 to 358.

† Geol. Sur. Mich. V, Pt. I, p. 38.

S. 13458.

Diabase altered to ferruginous kaolin. (Patton.)

Cleveland Mine, Lake Shaft. Sec. 20, T. 47, R. 27.

H. Sp. Dull greyish red rock, soft and greasy to the feel, and with strong earthy smell.

U. M. shows the diabasic structure as No. 13456. The feldspar laths, however, have been altered into a white earthy substance, so fine grained as to appear almost isotropic; the augite is altered into a dirty brown, colorless opaque earthy aggregate. This substance is partly white, partly black ore dust and largely brown hematite.

The original magnetite grains appear to have remained unaltered and in addition there have been formed a very few small grains of quartz.

That the main mass of this rock is kaolin, is to be seen by comparing with No. 13459.

No. 13459.

Diabase altered to kaolin.

Cleveland Mine, Lake Shaft. Sec. 20, T. 47, R. 27.

H. Sp. Fine grained; soft and earthy; color very light gray, almost white. When scratched the streak is reddish, due to the presence of small particles of red oxide of iron, which, when thus crushed, is spread on a greater surface. The rock has a slightly greasy feel, a strong earthy smell, and adheres strongly to the tongue.

U. M. The original diabase structure is even here still plainly preserved, but both feldspar and augite have been altered into an excessively fine powder like that in No. 13458, but which contains a smaller amount of discoloring iron oxide dust, and with which occur very small angular grains of quartz that form perhaps one-tenth of the whole mass.

Although the hand specimen is so light colored, there are still left apparently all the original grains of magnetite unaltered. These on account of the contrast in color appear to form much more of the bulk of the rock than is really the case.

Preliminary experiments were performed first with the blowpipe, afterwards by means of microchemical reactions with hydrofluoric acid, for the purpose of determining the nature of this white powder.

B. B. It is infusible, gives off water and becomes blue when ignited with cobaltic nitrate.

These tests which indicate the presence of alumina and water agree with those for kaolin, and were confirmed by the microchemical reactions. These latter gave no trace of potash, magnesia or soda, but showed the presence of silica and alumina.

If any doubt could exist as to this being kaolin, it is removed by the chemical analysis of the whole material of the rock made by Fred F. Sharpless of the Michigan Mining School.*

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*Below, p. 250.

In the analysis the amount of silica is, of course, augmented by the presence of free quartz. Of the iron oxides present all the FeO, 0.22%, and a proportionate amount of the Fe_2O_3, namely, 0.49%, is in the form of magnetite, which forms, therefore, 0.71% of the whole. As most analyses of kaolin show about 3% of Fe_2O_3, which, as in this case, is probably due to the presence of limonite, it is hardly worth while to consider separately the amount of this mineral. The remaining Fe_2O_3, therefore, namely, 2.07% will be thrown in with the kaolin.

To estimate what the relative amounts of kaolin and of quartz are, the average composition of kaolin was taken from Dana's Mineralogy and is given below.

$$\text{Average composition of 10 analyses of kaolin}\left\{\begin{array}{ll} \mathrm{SiO_2} & 47.60 \\ \begin{array}{l}\mathrm{Al_2O_3}\\ \mathrm{Fe_2O_3}\end{array} & \left.\begin{array}{r}35.75\\ 3.05\end{array}\right\}38.80 \\ \mathrm{H_2O} & 13.20 \end{array}\right.$$

This gives us the ratio between the sesquioxides, silica and water to be 38.80 : 47.60 : 13.20. Now as all the sesquioxides in this rock may be assumed to belong to kaolin, namely 30.73 % (28.66+2.07) the relative percentages of SiO_2 and H_2O required for the kaolin may be found by means of the above ratio; for instance,

$$R_2O_3 \text{ (Dana)} : R_2O_3 \text{ (found)} = SiO_2 \text{ (Dana)} : SiO_2 \text{ (required)}$$

$$38.80 : 30.73 = 47.60 : 37.50$$

Similarly for H_2O

$$38.80 : 30.73 = 13.20 : 10.43$$

hence we have

30.73	R_2O_3
37.50	SiO_2
10.43	H_2O
78.66% kaolin	

This represents the proportion of kaolin present in the rock under consideration. The remainder consists of about 1% magnetite and impurities and about 20% quartz.

In the above reckoning it is noticeable that the estimated amount of water, 10.43%, very closely agrees with that actually found, 10.50%, which may be taken as additional evidence that the white mineral is kaolin.

The chemical change which this diabase has undergone may best be seen by comparing the above analysis, which is here repeated, with that of the comparatively fresh rock, No. 13456.

From this table one might infer that there has been considerable gain in silica, alumina and water, and a loss of all other ingredients, but with the attainable data it is impossible to prove that the gain in part of the substances is a real one, with the exception, perhaps, of water. In this latter case the gain is too large to be explained away, and, further, an increase of water over that in the original rock is imperative for the formation of kaolin.

	I. No. 13456. Unaltered rock.	II. No. 13459. Altered rock.	III. Material apparently lost.	IV. Material apparently taken up.	V. Apparent percentage of gain.
SiO_2	47.99	58.22	....	10.23	21.32
Al_2O_3	16.57	28.66	....	12.09	72.90
Fe_2O_3	6.01	2.56	3.45		
FeO	5.13	0.22	4.91		
TiO_2	2.71	....	2.71		
MnO	trace				
CaO	9.36	0.17	9.19		
MgO	6.01	....	6.01		
K_2O	1.39	....	1.39		
Na_2O	2.00	....	2.00		
H_2O	2.64	10.52	....	7.88	298.48
Total	99.81	100.35			

If it were possible to prove that any one of the important ingredients had remained constant, or if it could be shown how great had been their loss or gain, it would be an easy task to figure out the actual loss or gain for all the other ingredients. In the absence of any such proof we may assume that a loss of silica is more probable than a gain, inasmuch as the alkalies and probably some other substances went off in the form of silicates. Further, if there has been an actual increase in the amount of silica there must have been a corresponding increase of $Al\ O_3$. This is highly improbable on account of the difficult solubility of this substance? On the other hand it is to be expected that this most stable of all the compounds present in the original would be affected least in the process of alteration.

Let us assume, therefore, that the Al_2O has remained constant.* It appears from column V in the above table that there has been an apparent gain in Al_2O_3 of 72.90% while the H_2O has increased 298.48%, but SiO_2 only 21.32%. The apparent increase in SiO_2 is less than one-third that of Al_2O_3, i. e., if Al_2O_3 has remained constant, as is probable, then there has been an actual loss of SiO_2. In other words, although the product of decomposition is much more acid than is the fresh rock, this acidity is gained by the loss of the basic elements and not by the increase of SiO_2.*

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* As do Merrill and Smyth, Bull. Geol. Soc. Am., volumes VI, VII and IX [Lane].

(c) Uralitic alteration.

In the common alteration of the rocks of this group I have not happened to observe any shearing action such as Williams found in one of his slides, S. 11616 (W).

Almost the first thing to change is the olivine. In none of the sections is this absolutely fresh. The margin and cracks became lined with secreted iron oxide granules, and little green fibres. These little green fibres wander off into cracks in the feldspar, and into the acid interstices. They may gradually increase until they replace the olivine entirely. They are pleochroic and have an optically positive elongation while non-pleochroic sections show a negative uniaxial image. The birefraction seems to mount about to 0.019 (S. 965) or to 0.017 (S. 909) as a maximum in the strongly pleochroic sections. This substance has undoubtedly been called serpentine, but careful study shows that it is rather foliated, that it has transition forms to brown mica, from which, or rather from green mica it differs only in the strength of its birefraction, or in other words that it is intermediate between biotite and chlorite. When it replaces the olivine it is sometimes uniform in orientation (See Fig. 29, which may be compared with Fig. 23).

Something like what we have described has been also mentioned by Brauns† and called villarsite. Since, however, that is a transference of an old name to a new sense, a doubtful proceeding, and we do not really know the composition of the mineral that we are dealing with, and inasmuch as it seems to me to belong in all probability to the morphotropic series of mica-serpentine-chlorite,‡ standing intermediate between them in optical properties, it seems to me that mica-serpentine or green mica will suffice for a name.

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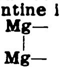
* It will be noted that the analyses of the fresh rock and the conclusions of Van Hise and Patton, worked independently and on different occurrences, are almost identical [Lane].

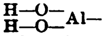
† Zeit. d. Deutsch. Geol. Ges., 1888, Vol. XI, p. 467.

‡ According to Clarke's investigations of the compositions of the silicates, Am. J. Sci., XLIII, (1892), p. 190; Bull. U. S. G. S., No. 125, olivine and serpentine, mica and chlorite have a close analogy in chemical construction, all being formed out of $R_{12}(SiO_4)_6$ with R in olivine Mg_{12}; with R in serpentine in part



$$\begin{array}{l} Mg- \\ \,| \\ Mg- \end{array}$$

, in part H-O-Mg—, in part H—; with R in chlorite made up of the same molecules as in serpentine and also the radical



$$\begin{array}{l} H-O- \\ H-O- \end{array} Al-$$

while in biotite in addition to the above bases we have an alkali radical containing (K — O — Al =) or something similar.

This change to green mica is not the only one that the olivine undergoes, although it always seems to be the first step after the secretion of iron oxides. In the center of the olivine pseudomorphs we have at times a colorless mineral of strong birefraction that I take to be talc. Carbonates also occur, and sometimes the olivine in alteration becomes pleochroic, yellow to reddish brown (Ss. 869, 941), apparently what has been called iddingsite.* This form of alteration seems to be more common, however, in the Keweenawan flows.

The beginning of the alteration of the augite is a fine lamellation or striation, parallel to the basis if it is changing to chlorite (Ss. 9290, 11735) or to the vertical axis if it is changing to uralite. The alteration spreads particularly from the olivine grains. Soon the change to uralite is fairly under way. At one stage the altered augite becomes almost opaque (S. 917), brownish, and fibrous (S. 906). Then working in from the margin it becomes greener (S. 936) and more clearly uralitic hornblende. At the same time the uralite encroaches on the feldspar (S. 917) and shows more distinct polarization colors. The color of the uralite near the feldspar has a more greenish or bluish green tinge (more alkali ?) while near iron oxides the color becomes more brownish (more iron ?) (Ss. 917, 991, 757). In the process of alteration occur grains of a yellowish epidote (S. 761), whose elongation appears invariably negative, i. e , it is probably flattened parallel to (100), and also twinned parallel to this face. The faces (001) and (101) also occur. Folia of brown mica occur (Ss. 11875, 937) at the margin or in adjacent interstices.

The first sign of alteration in the feldspar is generally its invasion along cracks by little folia, which at times exactly resemble the green mica that is produced from the alteration of the olivine, at other times seem like ordinary chlorite, and at other times (S. 880) pass distinctly into brown mica. Another type of alteration is shown in the occurrence of semi-globular brown micaceous patches (S. 11801). When the feldspar is very largely replaced (Ss. 907, 1071) the chloritic character of the replacing mineral is unmistakable, and with this chlorite is also associated an epidote, not so yellow as that which occurs in the chlorite that replaces augite, but more like zoisite in optical properties.

The iron oxides occur in two forms in the altered rocks. The large original grains of intergrown magnetite and ilmenite turn to the white opaque substance known as leucoxene. This change apparently begins with the ilmenite, and thus we have (S. 791) angular pseudomorphs of leucoxene striped with bands of iron oxide, a phenomenon often heretofore noted.*

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* Lawson, Bull. U. Cal., Geol. Dep., I, p. 31.

Beside these, sprinkled all over the rock, especially in the uralite, are minute granules of leucoxene and iron oxides.

Pyrite also occurs occasionally, but I have seen nothing absolutely decisive as to its primary or secondary origin.

§ 8. Teschenitic diabase.

The younger dikes of the iron-bearing or Huronian formations belong, as we have said, with great uniformity to the quartz diabase family just described and its immediate kindred marginal forms. The diabase granophyrites and olivine diabases are but slight chemical modifications, of no geological moment, and apparently of comparatively rare occurrence. All the other basic igneous rocks that have not suffered uralitization are but rare exceptions. There are the peridotites and serpentines, and the rocks grouped under the name of lamprophyre may be akin but are excessively altered and are, I feel confident, dike forms of peridotite. Then there are one or two rocks whose field relations are somewhat suspicious, and seem to be Keweenawan in type, and may be from the drift, as S. 1846 from T. 42, R 31, an anorthite rock; S. 10161, 430 paces N., 2000 paces W., Sec. 20, T. 43, R. 33. One peculiar type which I should expect to find rich in TiO_2 is S. 513, which we may provisionally call a teschenitic diabase. Its description is as follows:

S. 513. Teschenitic diabase.

(Diabase; Wright.)

Nineteen hundred eighty paces N., 1565 paces W., Sec. 6, T. 50, R. 30, at falls ten feet high.

Strike N. 70° W. Dip S. 70°.

H. Sp. Fine grained; massive; dark gray with the diabasic laths barely visible to the naked eye.

U. M. Shows abundant plagioclase laths with interstitial violet brownish augite, plates of hematite or ilmenite, considerable uniformly distributed idiomorphic brown mica. In addition there is much green substance of at least two kinds.

Accessory; apatite, carbonates, titanite.

The feldspar has the usual characters of diabase labradorite. It is much clouded, especially along cracks, etc., by little scales of the green substance that have the properties of sericite. Sometimes the sericitic matter is massed together in the interstices, in which case irregular aggregates of titanite (?) are enclosed. The interstices not filled with augite are, however, more commonly filled with a greenish substance of lower double refraction, in radiating (+) fibers.

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*Rosenbusch, Mik. Phys., I, Pl. XV., fig. 2; Wadsworth, Minn. Geol. Sur., Bull. II, p. 64.

The augite is rarely idiomorphic, but sometimes distinctly so. It is distinctly pleochroic, b always more reddish, while the other axes of pleochroism probably do not coincide with the optical axes. In the direction of the crystallographic axis, a. the light transmitted is light green. The color of the other axis is much like that || to b. The optical angle about c is moderate. One axis is much more dispersed that the other, and other sections show that it is the axis nearly parallel to the prism with $r > v$ as shown in Fig. 28.

The brown mica is thoroughly compact and idiomorphic, apparently uniaxial. Apatite needles are abundant.

This rock in its tephritic augite, primary biotite, abundant apatite, and peculiar alteration, has stronger affinities with the teschenites, than with the kersantites. I would still keep it in the diabase group as a teschenitic diabase.

§ 9. Diabase granophyrite.

A few sections and specimens may be referred to this rare petrographical type, which is probably only an extreme facies of the quartz diabases, since Williams's section from the Lighthouse Point dike, S. 11675 (W), seems from his description to have belonged to this type. This agrees with Rominger's remark that the supposed westward continuation of the Lighthouse Point dike contains more red feldspar.[*] Indeed it would not require much imagination nor twisting of the strikes to make the big dike at the Holyoke adit, Sec. 2, T. 48, R. 47, which we take as the type of the diabase granophyrites, continuous with the Lighthouse Point dike.

Some of the quartz diabases mentioned by Rosenbusch, and the Vosges "gang-granophyres" with labradorite[†] are probably similar. The relation to Lawson's diabases from the north shore of Lake Superior is discussed above and in § 11. F. D. Adams has also encountered similar rocks in Canada. As we shall see in § 11 when we take up the chemical relations of the group, though these rocks are chemically much more acid than normal basaltic rocks (see analysis No. VI, at the end of the chapter) and thus akin to the diorite porphyrites, in texture, mineral composition and geological occurrence they are an extreme form of the quartz diabases. Analysis VI shows much more iron and less alumina than the true intermediate rocks, as may be seen by comparing the analyses quoted in Zirkel's Lehrbuch der Petrographie, 1894, II, pp. 485, 503, 545, or the analyses of porphyrites given by Cross in his discussion of laccolitic rocks.*

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[*] Geol. Sur. Mich., IV, p. 147. To the kindness of Messrs. Sutton and Seaman I owe an opportunity of examining some sections from this locality, Sec. 16, T. 48, R. 25, near the Brewery, viz. Nos. 38194 6, 425 The augite, labradorite, micropegmatite, apatite, mica, etc., are as in 7931, and the micropegmatite is nearly or quite as abundant. There is much greater yellow staining and somewhat greater alteration of the augite. It should be said that the above gentlemen notice the micropegmatite mainly on top of the outcropping knob and take it to be secondary.

[†] Mik. Phys., 1896, II, pp. 1111, 1144, 649.

The following specimen is like this group, and very much like the salite diorites† but finer grained (augite about 1 mm. in diameter.)

No. 6963 (5716).

Quartz diabase, or augite granophyrite.

(Altered diabase; Wright.)

Six hundred fifteen paces N., 1992 paces W., Sec. 8, T. 47, R. 45; from pit No. 7, 18 feet from surface.

U. M. Is a moderately coarse rock with long slender reddened laths of oligoclase, and about equally long and slender light colored but much altered pyroxene. There are also grains of magnetite, sometimes apatite.

Interstitial: much quartz, orthoclase often granophyric, secondary epidote, chlorite.

The feldspar is always reddish, even in the granophyric growths. It is in spots replaced by a positive chlorite of considerable birefraction.

The feldspar extinctions are moderate (19°–14° with 9° in an albite Karlsbad twin).

The forms are very sharp. The twinning lamellæ are not numerous.

The pyroxene is altered into hornblende and chlorite. Both alterations proceed along the basis, and where we have (100) twinning as very often happens, give a herring bone pattern (augite extinctions 41°–43°, 41°–48°). The augite is often in stellate groups and there is one group which is composed of two orthopinacoid twins at right angles which suggests a twinning after $(\bar{1}11)$. The alteration is precisely that described by Törnebohm in the Konga diabase, and does not attack a brown marginal hornblende that occurs around the augite.

The quartz is in irregular grains with a granophyric border against the feldspar. When the micropegmatite shows, as often happens, rod shaped forms, these have ex. 0°. Most of the apatite, which has enclosures down the middle, lies in the micropegmatite.

The iron oxides are sometimes coated with leucoxene, and occur in large irregular grains, with indications of crystalline form.

The chlorite has essentially the same properties whether in the augite, the feldspar or, as happens to a limited extent, filling the interstices with an irregular aggregate of fibers. It often borders the feldspar all around. When it enters the feldspar it willingly follows the twinning lines parallel to the elongation in marked contrast to its arrangement in augite.

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* Fourteenth Annual Report, U. S. G. S., p. 227.

† See footnote at end of section.

This rock answers to the quartz, i. e., Konga diabase of Törnebohm most nearly in the idiomorphic augite with (100) twinning and decomposition, in the apatite and the magnetite, and the quartz and the granophyric growths. The only point of difference is that the pyroxene is here mostly light colored but it seems to me that the blanching may be a first step toward alteration. The brownish hornblende also occurs so irregularly at the margin of the feldspar that that might be secondary too. The rock must, however, be extremely acid for a diabase. Some of Irving's augite syenites are probably akin; it is weathered but not metamorphosed.

S. 14631, 455 paces N., 1325 paces W., Sec. 35, T. 49, R. 27, is probably of the same group; the augite is wholly changed to chlorite.

S. 7931.

Quartz diabase, granophyrite; Patton.

(Diabase; Wright).

Twelve hundred sixty paces N., 460 paces W., Sec. 2, T. 48, R. 27. Dike in ravine.

H. Sp. Medium grained; massive; very dark green, with reddish spots.

U. M. Shows the structure of a tholeyite, namely long lath shaped plagioclase, with mostly allotriomorphic grains of augite, iron ore, and a little brown biotite, and a well developed mesostasis. The mesostasis is here unusually abundant, occupying about one-third of the whole. It consists essentially of a beautifully granophyric intergrowth of quartz and feldspar (Pl. XVI) (probably orthoclase*), with which occurs here and there a grain or two of quartz, and a greenish, often radiated aggregate of a micaceous mineral having the pleochroism of chlorite. Very characteristic for these acid interstices are very long threadlike needles of apatite which pierce through granophyric aggregate and mica and often extend out into the main rock, cutting into or through feldspar and augite. Frequently half a dozen or more needles run parallel to each other, looking like scratches in the slide.

The feldspar of the granophyric interstices shows no twin striae. It is stained a deep reddish brown.

The feldspar (labradorite) is the only ingredient which possesses idiomorphic form. All others are irregular in shape except where they come directly in contact with the acid interstices.

The augite is of a light violet green color. It shows sometimes an alteration into brown hornblende. This seems to take place next to the acid interstices. More usually it shows an alteration into a slightly greenish substance which penetrates from the edges into the augite grain. Only in sections parallel to the clinopinacoid (010) does the substance appear to assume definite shape.

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* Determination by Becke's test shows that, as is generally true in the micropegmatite, the greater index of the feldspar is less than the less index of the associated quartz, and so it must be either albite or orthoclase, and the K_2O in this specimen (analysis VI at the end of § 11) shows that it is the latter when we consider how much soda is required for the labradorite. [Lane.]

Here it has a fibrous appearance, the fibers being parallel with the basis of the augite. It shows an extinction angle of about 20° and has a double refraction about equal to that of hornblende. (The extinction is inclined 20° to the basis of the augite.)

The relative ages of the plagioclase and augite are uncertain, for the augite, though mostly of irregular shape, often encroaches to a slight extent upon the plagioclase.

This rock is an extreme form of the granophyric quartz diabases, but seems worthy of a special name.*

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* Bayley's reference to quartz diabase, U. S. G. S., Mon. XXVIII, pp. 519-520, comes to hand while this volume is in press, just in time for notice. The occurrence which he takes as a type of quartz diabase, I had considered best described as an augite (salite) diorite and had not intended to include it in this group, although I had written "this rock resembles the uralite granophyrite" (see above, p. 255). "No. 6963 very markedly and hence is connected with the diabase granophyrites of which it may be an extreme form." Dr. Hubbard indeed was inclined to class it as a syenite, and on revision I am inclined to agree with him and a reference to augite syenite would not be unnatural. It is referred to by Brooks, Wis. Geol. Sur., 1879, III, p. 568, as related to the Picnic Point rocks near Marquette, which have been called porphyritic hornblende diorite, hornblendic syenite by Wichmann, porphyritic syenite by Rutley, diorite or amphibole granite by G. H. Williams (U. S. G. S., Bull. 62). As Bayley's map shows, its occurrence is in a small massif over one-quarter of a mile in diameter. It may be related to the normal quartz diabase somewhat as the melaphyre porphyrite is to the ophites, but in addition it is decidedly more like a deep-seated plutonic rock. Our section 13024 is considerably coarser grained than any of Bayley's (Nos. 16748, 16750, 16890), however. Bayley's sections are as fine for illustration of micropegmatite as I have seen, and they are remarkable for the exceeding fineness of the interdigitation of quartz and orthoclase which is at times almost submicroscopic, and finer than usual in the quartz diabases. I have also been permitted to see the sections of the Michigan College of Mines, Nos. 38300-38360, from this same knob.

The hand specimen shows blades of a dark augite, hard, but without the silky lustre of hornblende. These blades are up to 12 mm long, or more, and often about 10 mm. In nearly equal proportions a red feldspar is present, which is often in narrow striated laths, in lengths running 5, 4, 3, 3 mm, and but a mm. or so broad. Under the microscope we see long laths of acid oligoclase or orthoclase, which run out into marginal intergrowths with interstitial quartz. There is also chloritized green mica with well marked halos, ilmenite partly changed into leucoxene, and most remarkable of all very long crystals of colorless pyroxene much decomposed, but changing into a greenish brown mica and generally not into hornblende. The pyroxene seems to have had originally an hourglass form, with the outer layers most liable to attack and hence more changed into mica.

So far as the general question of the origin of micropegmatite is concerned, Bayley's sections, especially No. 16750, certainly show cases where the micropegmatite appears to replace the older feldspar, and I presume one inclined to that opinion would look at them as proofs of the secondary origin of the feldspar. And yet I cannot rid my mind of the conception that it is a magmatic action, that the older feldspar has been attacked and corroded in the fashion described by Michel Lévy. (Roches Éruptives, pp. 3, 4; Cf. Ros., 1896, II, pp. 216-230.) However, whether secondary or magmatic in origin, it is much easier chemically to conceive of a saturation of a potash feldspar by quartz in such way as to convert it to micropegmatite than of a labradorite, and in this Michigamme knob even the older feldspar which apparently has been corroded, and is replaced by micropegmatite, is largely orthoclase (not twinned, both indices of refraction much less than the lower index of quartz, appropriate extinctions, microcline structure occasionally visible but mainly in the younger fresh generation) or albite, $Ab_{19}An_1$ (about 5% An, Manebach twins very common, also pericline, Karlsbad and albite laws). The greater index of refraction is very close to the lower one of quartz, the lower index much less;

Extinctions	+4°	+9°	with 13°	+7°	Karlsbad
	8°	−16°	with	−12°	Karlsbad
	9°	−13	with 9°	−9°	Karlsbad
	9°	11°	with 16°	−5°	
	23°	−14°	with 10°	+17°	
	10°	−10°			
	8°	−4°)			

Hence in this knob one difficulty in the way of accepting the secondary origin of micropegmatite, viz., the rarity so far as reported of a secondary alteration which increases the percentage of potash (Cf. Merrill, Rocks, Rock Weathering and Soils, and C. H. Smyth, Bull. Geol. Soc. Am., IX, p. 257), is removed.

It should also be said that Bayley's sections are distinctly finer grained than mine. The feldspar does not occur in diabasic laths but in hypidiomorphic rectangular areas with occasional longer laths, as in granite. Similar may be the occurrences of micropegmatite cited in Ros. 1896, II, pp. 215, 219. If we assume all igneous rocks to be derived by liquefaction of a solid crust by relief of pressure, as I am inclined to think (Bull. Geol. Soc. Am. V, p. 269), the appearance of the micropegmatite could be explained as due to a relief of pressure leading to the corrosion of the earlier crystals, followed by speedy solidification of the partially liquefied rock as micropegmatite. But it is also conceivable that the potash which is leached out in ordinary weathering may be deposited in the shape of micropegmatite at greater depths. But unless these depths are very considerable I cannot understand why the micropegmatite is so confined to intrusive rocks as it seems to be.

Tabulated observations by Lane on dike of Holyoke adit.

No. of dike.	Composition and character of feldspar.	Extinction angles observed in twins.	Size of feldspar in mm.	Size of augite grains.	Size of magnetite.
7931	Ab$_1$An$_1$: moderate extinctions but lower than usual in quartz diabase.	21° 17°-21° 14°-10° 30° 19°-14° 9°	1 x 0.4		
7940	Small extinction angles.		0.40 x 0.1 0.3 0.03 0.6 0.1 av. 0.4 x 0.08		
7954	Ab$_2$An$_1$ small extinction angle.	0° 0° 0°	0.6 0.01 0.4 0.1 av. 0.25	0.3 x 0.2 near margin.	
7957	Ab$_1$An$_1$.	0° 15°-21°	1.3 x 0.2 1.0 x 0.3	0.7 x 0.3 0.5	near center
14604	Ab$_2$An$_1$: small extinction angles.	0°- 0° 0°-10° 0°-15° 2°- 4°	1.8 0.2 1.4 0.3 2.0 0.3 1.7 0.3	0.5 0.6 0.4 0.3 0.4 0.3 0.38	0.3 0.3 0.5 0.2 0.5 0.2 0.33

§ 10. Contact action of diabases.

The various diabases probably have the same contact action, regardless of the variety to which they belong. The considerable variety in the character of the contact zones seems due rather to the different character of the country rock or to the different physical conditions at the time of the formation of the contact zones. At any rate we have not noticed any connection between the character of the intrusive rock and the varying character of the contact.

(a) Production of touchstone or lydianstone.

Perhaps the most simple form of contact zone occurs in the slates, when the rock adjacent to the dike is simply indurated, so that the cleavage is destroyed, and is replaced by a conchoidal fracture, while the rock becomes much harder—in fact a regular touchstone, i. e., lydianstone or basanite. Such contacts are illustrated by specimens between Sp. 407 and Sp. 415, T. 48, R. 28, and between Sp. 382 and Sp. 392, about 225 paces N., 825 W., T. 49, R. 28 and by Sps. 10155, 10166, 10312, but is perhaps best studied in S 9396, 920 paces N., 550 paces W., and S. 9397, 925 paces N., 555 paces W., Sec. 28, T. 51, R. 31, altered by the olivine diabase dike represented by S. 9398.*

The unaltered rock is represented by S. 9395, 1940 paces N., 1478 paces W., Sec. 23, T. 51, R. 31, from the slate quarry not far off. It is a common black slate, with no apparent grain, very slaty, yet the cleavage is not perfectly smooth. A joint plane is coated with pyrites. Under the microscope it shows a cryptocrystalline quartz-feldspar aggregate, with minute folia of mica, and chlorite, and is much clouded with irregular black carbonaceous dust. There are in it also recognizable grains of leucoxene and iron oxide and minute prisms of tourmaline such as characteristically occur in these slates, doubly terminated, 0 R (or ± ½ R) bluish; brown, R, antilogous.

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*Cf. Bull. Denison University, II, 1887, Pt. 2, p. 127.

Now Sp. 9396 has no apparent grain nor cleavage, but a flat conchoidal fracture, full of glistening points, which give it a more siliceous appearance, and it is indeed harder than 6, and is a genuine touchstone. Under the microscope we see that the rock appears very much clearer, and more like the secondary ground mosaic of a quartz porphyry. The mica folia appear fewer but better defined and the tourmaline somewhat scarcer. This last fact may not be connected with the contact zone, however.

The rock producing this alteration is an ophitic olivine diabase, with the olivine thoroughly altered. In this connection should be mentioned Sp. 9397, a graywacke, which is farther from the contact line but appears somewhat indurated and reddened as by igneous contact.

(b) Spilositic alteration. A somewhat different alteration is illustrated by Ss. 13776 to 13779 of Sec. 9, T. 51, R. 31, and also by S. 9323, about six feet from the contact with Sp. 9324 (a quartz diabase), 200 paces N., 1900 paces W., Sec. 22, T. 50, R. 33,—also by S. 9327, 300 paces N., 1420 paces W., Sec. 22, T. 50, R. 33, near which is Sp. 9326. Sp. 13323 is akin.*

S. 9323 is a coarsely fissile rock, dark gray, turning lighter brownish green, and under the microscope appearing to be a very fine grained chloritic rock, peppered over with iron oxides, showing some sericite and a quartz-feldspar background which extinguishes in flecks. There is also some leucoxene and not a little of the carbonates. The flecks appear due to a prevalence of green mica over chlorite and a somewhat coarser quartz-feldspar aggregate. Between the flecks the aggregate, through its self-compensating action, gives low polarization colors and the chlorite is of course almost isotropic. No trace of the flecked appearance can be seen without the nicols.

In S. 9327 the spilositic flecked texture is much more pronounced. Chlorite is absent and sericite or kaolin abundant in the flecks, and immediately about them is a darker zone of iron oxides and chlorite. The margins are clear and the center rusty with iron oxides. To the naked eye the round reddish flecks on a greyish green ground are plain and very abundant. The rock is highly fissile, soft, and has a strong earthy smell.

(c) Alteration of granite. Upon granite these diabases produce a reddening which is shown in Sp. 382 and Sp. 383A from Sec. 19, T. 49, R.

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*See Geol. Sur. Mich., V, Pt. I, p. 66; Cf. Analyses D. and E., U. S. G. S., Bull. No. 148, p. 97.

28, but especially well by the following suite: Sp. 11801, a fresh quartz diabase dike, 40 paces N., 850 paces W., Sec. 3, T. 48, R. 25; Sp. 11802. a piece of the same, enclosing a small reddened fragment of the granite gneiss; Sp. 11804, a piece of reddened granite from the contact; Sp. 11806, a piece of a granite dike in the granite gneiss, which is itself altered in the same way.

To the naked eye the main feature is the reddening already mentioned, and the microscope does not show much more alteration. The descriptions of Ss. 11802 and 11804 will be sufficient. They are as follows:—

S. 11802.

Gneiss reddened by the visible contact of the marginal facies of a quartz diabase, No. 11801.

Thirty paces N., 850 paces W., Sec. 3, T. 48, R. 25. Contact of dike with granite on S. side. For a distance of from 2 to 4 feet on each side of the dike the granite is very red.

H. Sp. Shows a reddened granitic patch adjoining a very fine grained porphyritic blue-black trap like No. 11762.

U. M. Is composed of quartz, reddish discolored feldspar, brown mica, chlorite and carbonates.

Accessory: apatite.

Encircling about half the slide, as a rim, is a narrow zone of a basic rock with ferruginous base and sharply outlined little laths of plagioclase that have but two or three lamellæ. Immediately adjacent to this the grains of quartz interlock, are small and discolored with carbonates, but we pass immediately into larger, irregular grains of quartz, that show undulous extinction. The feldspar, at times plagioclase, is heavily clouded, especially at the margin, with orange-colored ferrites.

The apatite occurs but seldom, and then in fairly large grains. Chlorite, carbonates, etc., occur as rare accessories.

S. 11804.

Gneiss, reddened by contact.

Thirty paces N., 850 paces W., Sec. 3, T. 48, R. 25.

Granite in direct contact with dike.

H. Sp. Medium grained; massive; brick red.

U. M. Consists of reddish discolored feldspar (orthoclase and oligoclase?), quartz, and a little mica-chlorite or serpentine.

Accessory; iron oxide, zircon, apatite, carbonates.

The feldspar and quartz are not intimately mixed, but in separate although interlocking patches, the patches of quartz being rather rounded and from 2 to 3 mm. across.

The reddish discoloration is confined mainly to the margin of the feldspar. Otherwise the feldspar is fresh. There is one Karlsbad twin, and not infrequently there occur very narrow and numerous lamellæ that show the albite law (indicating a soda-lime feldspar).

The quartz is almost free from the reddish discoloration, but it is full of lines of enclosures, mainly gas, or liquid with much gas. It also contains zircon and other irregular grains that have strong optical powers (a Ti-mineral?).

The lines of enclosures pass through different grains of the same quartz patch indifferently, but only occasionally pass through to another patch.

The small amount of interstitial green substance that occurs has a yellowish green color, positive fibers, and birefraction more than that of quartz. It is distinctly dichroic, with greater absorption parallel c, and acts like serpentine.

Apatite is not abundant, but when it does occur, it is in grains just visible to the naked eye.

Carbonates are mixed in with the serpentine.

(d) Adinoles (?).

Another less common alteration, not so certainly attributable to the diabase, consists in the production of cherty bands which are not black, but vary from white to flesh-colored tints. They are then indistinguishable to the naked eye from some of the jaspers of the iron-bearing rocks. Sp. 11868 seems to be a rock from this class, and appears to have been altered by the dike represented by Sp. 11865. The presence of a considerable quantity of feldspar brings it in the class of adinoles, and separates it from the jaspers and hornstones. It can be recognized only with difficulty by the microscope, being more certainly identified by tests for soda. Sp. 11828 may have been thus altered by Sp. 11827; its description is as follows:—

No. 11828.

Adinole or chert.

Eight hundred paces N., 875 paces W., Sec. 2, T. 47, R. 25.

Dolomite schist, impregnated with sulphuret of copper.

H. Sp. Is associated with a vein containing chalcocite and chalcopyrite; aphanitic; massive, but banded; brownish.

U. M. Is composed of minute grains (.02mm.) of quartz and feldspars on a fine grained micaceous ground full of grains of pyrite.

Accessory: iron oxide, large folia of white mica.

The grains of quartz and feldspar are of irregular form and distribution, parts of the groundmass being apparently quite free from them. They are both quite clear and can be distinguished only in convergent light, or by the occasional appearance of albite lamellæ. Feldspars appear to predominate. The finer grained micaceous mass has a brownish hue and a parallel arrangement with abundant random scales. Now and then a large random leaflet of a much clearer mica occurs.

The iron oxide grains are irregular.

The pyrite is in irregular patches of brassy lustre and is very abundant.

This is apparently a sericite schist, but the hand specimen shows that it is an indurated chert (or adinole). The induration may not be due to the dike, however.

(e) Sillimanitic schist.

Another interesting rock which appears to be due to the contact action of the continuation of the Lighthouse Point dike is S. 963. This sillimanitic hornstone appears to be due to the influence of S. 962 on the hornblende schist, S. 964. The descriptions of the specimens are as follows: —

S. 962.

(Basalt melaphyre; Wadsworth. Diabase; Wright.)

Sec. 23, T. 48, R. 25.

South side of Michigan St. Contact of diorite schist on the north and diabase on the south.

H. Sp. Much finer grained at one side; massive; bluish black. (Breaks with a conchoidal fracture, weathers brownish, and shows porphyritically enclosed lath shaped feldspars. Wadsworth.)

U. M. Porphyritic greenish pseudomorphs of olivine and laths of labradorite may be seen. The latter grade into the laths of the ground, which contains in addition augite in granules and spherulitic sheaves, octahedra and rarely skeleta of magnetite, and probably a little glass.

Olivine in idiomorphic forms has been replaced by a greenish dichroic substance (apparently uniaxial, with strong double refraction, pleochroism, 𝔞, yellow, 𝔠 or 𝔟 green as in Fig. 29).

The labradorite laths are as in S. 949, and the augite has the same tendency, there noticed, to undulous extinction. The augite granules fit loosely together. This implies the presence of glass.

S. 963.

Hornstone.

(Schist, amphibole schist; Wadsworth. Diabase; Wright.)

Sec. 23, T. 48, R. 25. South side of Michigan St. Contact with diorite schist.

H. Sp. Aphanitic black slate; banded; indurated. There is a very harsh feel in grinding the rock. Some very hard mineral must be enclosed. This also points to sillimanite. (The specimen is produced as a contact alteration of the diabase, No. 965, with an amphibole schist. Wadsworth.)

U. M. Is a schistose rock with outlines of large porphyritic feldspar, and a greenish ground containing quartz, brown mica, etc. The whole slide is thickly strewn with minute prisms of (possibly corundum) sillimanite. The minute prisms of sillimanite cloud the feldspar beyond exact identification. In the feldspar they are all parallel (+ ex. 0°, yellowish color, strong refraction, but only moderate double refraction). They would be taken for epidote or zoisite if it were not for the uniformly + extinction. In those minerals it is generally negative. There is no other mineral, with the properties of this one, but sillimanite. Moreover, it does not seem soluble in HF. The green part of the ground is somewhat opaque, with a granular structure and nearly isotropic. On this greenish opaque ground are clear dots of quartz and black irregular dots of magnetite. I should think this a contact alteration of a porphyrite, which may have been previously dynamometamorphosed and I should look for contact action.

S. 964.

Hornblende schist.

(Schist, amphibole schist; Wadsworth. Diorite schist; Wright.)

Sec. 23, T. 48, R. 25, south side of Michigan street, 2 feet from contact with diabase, i. e., the comparatively unaltered rock.

H. Sp. Very fine grained; dense; dark greenish gray.

U. M. Is a uniform non-porphyritic rock, which contains very slender prisms of trichroic hornblende that interlace, with a general parallelism, on a fine grained quartz-feldspar mosaic. There are scattered grains of iron oxide, sometimes in nests with leucoxene.

Other accessories seem to be lacking. The hornblende varies somewhat in color; the larger slender prisms are quite dark bluish to deep green.

(f) Salite bands in hornblende schist?

Finally it is barely possible that such salitic bands as occur in hornblende schists and are illustrated by Sp. 492, may be due to the influence of diabases like Sp. 497. The description of S. 492 is as follows:—

No. 492.

Salitic hornblende schist.

(Diorite schist; Wright.)

Five hundred paces N., 125 paces W., Sec. 27, T. 50, R. 28. Strike N. 45° W. Dip vertical.

H. Sp. Very fine grained; slightly schistose, with lustrous foliation planes, a reddish feldspar vein, and a lighter greenish band in which the salite probably occurs.

U. M. Shows irregular prismatic grains of hornblende, abundant interlocking feldspar and much iron oxide and leucoxene in the form of a fine dust. In part of the slide the hornblende is replaced by a light green pyroxene (salite?).

Accessory; apatite, titanite in grains, epidote.

The hornblende is the common kind and occurs in prisms or in large patches which are in this slide all cut nearly at right angles to b (100) ($-2V = 75°$ and $\mathfrak{c} - \mathfrak{a} = .018$ to $.028$; + ex. = 18°). Sometimes it and the salite are in parallel intergrowths.

The salite has the higher birefraction, but not the peculiar tints due to dispersion that epidote has. The cleavage is well developed and the extinction angle large. It has a peculiar light greenish tone and is not perceptibly pleochroic. The refraction is high.

The interlocking feldspar is much altered, having small micaceous folia, and a reddish discoloration. Here and there granules of leucoxene and epidote occur.

Titanite occurs also in large, light, recognizable grains. Apatite occurs in small sharp grains at times imbedded in hornblende.

§ 11. Chemical relations.

If we study the table of analyses given below, we note how extremely alike [*] the first five analyses are, and in Bull. No. 148 of the U. S. G. S. many similar analyses may be found (N., p. 70; A., p. 90, rather more silica, as most of the triassic diabases have; E., p. 185; E., p. 190; L., p. 200; etc.). But the five chosen, though widely separated geographically, belong to very nearly the same epoch. We note again, comparing them with the table of analyses in Chapter IX, p. 215, taking the average of the analyses, that they so strongly resemble those analyses of flows, that I cannot see any characteristic difference.

The inverse relation of magnesia and alumina noted in all the analyses is probably due to imperfect separation, an analytical error.

We can see, too, comparing VI with Shutt's analyses, VII and VIII, that the diabase granophyrite stands in the same relation to the ordinary diabases as the center of the Lawson dikes to the margin. There is an increase of soda, potash and silica toward the center. This is all we can be sure of, considering the imperfect character of the analyses. Still it does not seem likely that the alumina increases with the alkalies as in Iddings's absarokite series (Am. Jour. Geol., 1895, III, p. 935). If we contrast the differentiation already studied in the flows in chapter IX we see that that also is of a different character, for there the lime and soda vary somewhat as they do here, but there is no equally important concomitant change in silica. In fact it requires some imagination to detect a concomitant change of silica at all. Moreover, the potash increases in the dikes as it does not appreciably in the flows. This difference in the chemical character of the differentiation corresponds to a mineralogical difference, for in the case of the flows it is principally a question of the relative abundance of augite and feldspar, whereas in the dikes free quartz and orthoclase occur. It is hardly safe to say whether the difference in attitude, pressure, temperature, or of aqueous vapor retained determines the difference in differentiation, though I should think that the latter factor might be especially important in affecting the distribution of silica. One might easily imagine that the force of gravity affected the separation and settling of the heavier augite in the flows, while in the dike the differentiation was due to the segregation toward the center of that part of the magma most soluble in a trifle of superheated water. One has only to watch the behavior of superheated solutions of sugar, in other words, candy syrups, to see how a very little water may serve as solvent for vastly more than its bulk of solid. The following extract from Dudley's presidential address to the American Chemical Society is suggestive.*

---

[*] With the exception of the alumina in Shutt's analyses which must be incorrect, including MgO, and perhaps iron, for there is nearly enough alumina to make the rock with the given proportion of CaO: Na_2O (Cf. Pl. V) all feldspar, whereas we know from the descriptions and figures that there is a large amount of augite and other less aluminous constituents. (Cf. Pirsson, Am. Jour. of Geol., 1896, IV, p. 689.)

" * * in most modern steel works large ingots are now the rule, and in large ingots, which take considerable time to solidify from the molten condition, analyses show that some of the constituents of the steel are not uniformly disseminated throughout the mass. This separation of the constituents during cooling, technically known as 'segregation,' is characteristic of the carbon, the phosphorus and the sulphur. Furthermore the segregation appears to be worst in the upper third of the ingot,"—as in the upper part of Keweenawan sheets.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
SiO_2	47.99	47.90	47.83	47.50	46.94	54.11	57.50	52.47	58.22	41.60
TiO_2	2.71	0.82	....	....	....	0.85	....	....	....	3.79
Al_2O_3	16.57	15.60	†30.28	†22.44	16.91	12.09	†23.44	†25.54	28.66	37.20
Fe_2O_3	6.01	3.69	4.57	7.40	12.53	4.00	5.07	6.31	2.56	3.21
FeO	5.13	8.41	....	....	4.16	11.51	....	....	0.22	0.30
MgO	6.01	8.11	4.32	3.71	8.20	3.47	2.76	2.31	....	0.02
CaO	9.36	9.99	6.72	10.21	9.00	6.72	5.62	6.62	0.17	0.23
Na_2O	2.00	2.05	1.30	1.62	2.15	2.73	2.01	3.23	....	0.07
K_2O	1.39	0.23	tr.	1.29	0.54	1.49	0.45	0.54		
H_2O	2.64	2.49	loss 2.05	loss 2.85	loss 0.26	1.39	loss 2.25	loss 1.28	10.50	13.83
P_2O_5	....	0.13	2.19	0.34	0.28	0.12	2.02	1.16	....	0.14
Sum	*99.90	100.15	99.26	97.36	*100.75	99.23	101.12	99.46	100.33	100.85
Sp. Wt.	....	....	3.028	2.927	....	....	2.856	2.870		

*Summation incorrect in original reference.

† Erroneous.

I. Sp. 13456, Lake Shaft, Cleveland Mine, Sec. 10, T. 47 N., R. 27 W.; analyst, Sharpless, Geol. Sur. Mich. Ann. Report 1891, p. 141; with MnO_2 tr.

II. Sp. 12880, Sec. 13, T. 47 N., R. 46 W., Mich.; Analyst, Chatard, Van Hise, U. S. G. S., Mon. XIX, p. 357, Bull. 148, p.103, with trace Cr_2O_3; 0.10 NiO (CoO); 0.17 MnO; 0.38 CO_2; 0.03 SO_3; 0.05 BaO; feldspar also analyzed = Ab_2An_3 (*loc.*

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*Science, N. S. (Feb. 11, '98) No. 163, Vol. VII, p. 188.

cit., p. 352. I do not think it admissible to include in the feldspar the iron with alumina, and magnesia with lime.)

III. Stop Island dike near wall: F. J. Shutt, analyst; Lawson, Am. Geol., VII, 1891, p. 158. Lawson has some six more or less complete analyses of the same type as III and IV.

IV. White Fish Bay: analyst, Shutt, *loc. cit.*, p. 161; near contact.

V. Center of olivine bearing diabase, Skrainka: Missouri Geol. Sur., IX, Mine La Motte sheet, p. 38.

VI. Sp. 7931, diabase granophyrite: analyst, Sharpless, *loc. cit.* 1891, p. 134, with MnO 0.73, Cl. 0.02.

VII. Center of Stop Island dike, Shutt, *loc. cit.*, p. 158, also intermediate analyses.

VIII. Center of White Fish Bay dike, 60 feet from contact, Shutt, *loc. cit.*

IX. Sp. 13459, kaolitic alteration of Sp. 13456, Sharpless, *loc. cit.*, p. 141.

X. Sp. 12966, kaolitic alteration; Aurora Mine, N. E. ¼, S. W. ¼, Sec. 23, T. 47. N., R. 47 W.; Chatard, *loc. cit.* with 0.38 CO_2; 0.08 MnO; tr. BaO. He also gives intermediate stadium analysis.

In Proc. A. A. A. S., 1875, B. p. 60, is an analysis from Lighthouse Point, Marquette, which may be a poor partial analysis of the dike. It agrees with the others in SiO_2, but there are a large number of greenstones of various ages on this point. See Pl. XV.

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GEOLOGICAL SURVEY OF MICHIGAN

VOL. VI

PART II

KEWEENAW POINT

WITH PARTICULAR REFERENCE TO

THE FELSITES AND THEIR ASSOCIATED ROCKS

BY

LUCIUS L. HUBBARD

State Geologist

ACCOMPANIED BY TEN PLATES AND ELEVEN FIGURES

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ERRATA

PART II

Page 5, 11th line from the top, for "amydaloids" read "amygdaloids."
Page 8, 2d line from the top, for "poryhyry" read "porphyry."
Page 26, 12th line from the top, for "microscopically" read "macroscopically."
Page 75, 13th line from the bottom, for "phenochrysts" read "phenocrysts."
Page 94, 10th line from the top, for "occurrance" read "occurrence."
Page 117, 7th line from the top, for "anothar" read "another."
Page 131, 19th line from the top, for "egularly" read "regularly."
Page 140, 3d line from the right, for "distances" read "distances."

CHAPTER I

INTRODUCTORY

§ 1. Scope of field work.

During the progress of field work in late years by the Michigan Geological Survey on Keweenaw Point the observation was made, that the course of one or more conglomerate beds low down in the Keweenaw series was very irregular as compared with similar beds higher in the series, and this irregularity led to the belief that intrusions of igneous material might have taken place early in the geological history of the series, which, alone, might have produced an apparent unconformity or, in connection with subsequent erosion, a real unconformity which would call for a further subdivision of the series. Some phenomena observed on Isle Royale seemed to lend weight to the former, the simpler of these hypotheses, and plans were made to examine the lower or older parts of the formation to obtain evidence that might solve the problem, or that might throw light on the mutual relations of Keweenaw Point and Isle Royale. On a reconnoissance trip made to the end of Keweenaw Point in May, 1895, an area amounting to nearly one square mile, on the Little Montreal River, just above its mouth, was found to have been burnt over several years before, and the frequent exposures of rock there gave promise of yielding some facts which owing to the thick covering of forest had thitherto been inaccessible. The work during the remainder of the field season was prosecuted in that region and was confined largely to the two tiers of sections next north of Lake Superior, between Secs. 23 and 26, T. 58, R. 29, and the extreme end of Keweenaw Point. In 1896 the work was taken up at Mt. Houghton and was extended westward and southward along the same general horizon, particular attention being paid to the various outcrops of original acid rocks (and associated beds) which occur therein with greater or less frequency, as well as to the conglomerates.

In the prosecution of this work I have occasionally been assisted by the members of the Survey corps, and by Prof. A. E. Seaman to whose efficient aid I desire to express my indebtedness. I am also under obligations, for valuable old maps showing geological data, to R. R. Goodell, Esq., and to Mrs. Hill, widow of the late Hon. S. W. Hill, and for much useful information to Captains J. C. Hodgson and Johnson Vivian, and others.

§ 2. Structure of Keweenaw Point.

The geology of Keweenaw Point has been so often and so well described that a résumé here, even of only its salient points, may seem superfluous, but in view of the fact that the literature on this subject may not be readily accessible to everyone, I venture to lay before my readers, very briefly, enough facts to enable them to follow, easily and intelligently, the course I shall take in commenting upon the conclusions of others and in recording my own observations.

The west end of the Lake Superior basin is a broad synclinal bordered by rocks both of the Keweenaw or copper-bearing and Potsdam series, the former of which terminates about a hundred miles southwest of the lake in Wisconsin. Keweenaw Point and Isle Royale, near the east end of the main complex (we thus exclude from consideration a few isolated areas of volcanic rocks and the sandstone, at the east end of the lake), form the principal subjects of this volume. They exemplify the synclinal structure, the beds of Isle Royale dipping southeast, and those of Keweenaw Point northwest and northerly, each towards the lake. Keweenaw Point is the more typically representative of the two, in that it shows numerous outcrops of the more acid rocks and a contact, on the southeast, with sandstone recognized as Potsdam, and, what is of still greater interest, the relations of its rocks are such that they may enable us to explain some of the geological changes that have contributed directly to its topography and physical structure, and inferentially perhaps to the history of other parts of the Keweenaw series. The Minnesota coast northwest of Isle Royale corresponds more nearly to Keweenaw Point, in its general structure, but lies without the province of this report.

The Keweenaw peninsula extends about seventy miles northeasterly into Lake Superior from the fifth correction line at the head of Keweenaw Bay. A belt of rocks, in great part of volcanic origin, forming a plateau in many places 600 feet and upwards above lake level, dominates the central parts of this land spur, flanked by broad belts of sandstone whose drift-covered surface slopes on either side to the shores of Lake Superior. This plateau is cut in two, east and west, by the narrow bed of Portage Lake, and again sinks to within 250 feet of lake level at what I shall call Allouez Gap, near the headwaters of Trap Rock River. From this point rising again, it soon divides into two ranges separated by the valleys of Eagle River and the Little Montreal; the northern or Greenstone range with a very steep east-south escarpment skirts the lake shore on the west and north there, soon losing the broad belt of sandstone that formed its western flank further south, while the southern or Bohemian range continues in contact on the east and south with the great body of the Potsdam sandstone, or with isolated remnants thereof, almost to the extremity of the Point.

The Keweenaw series embraces volcanic rocks of different chemical and physical constitutions, from very basic to very acid, and from very fine grained to very coarse grained. With these are associated conglomerates and sandstones, which are also acid or basic, coarse grained or fine. The strike of these beds, with some notable exceptions, conforms nearly to the northerly coast line or trend of the Point, and their dip, which is variable in amount from place to place, is, as above stated, towards the main body of the lake.

Beginning near the end of the Point at the bottom of the series as exposed, at the contact with the Potsdam or Eastern sandstone, we find in the Bohemian Range a succession of both basic and acid volcanics, frequently in alternation with detrital beds of similar composition, the whole capped by an extensive and rather persistent bed of fairly coarse and rather acid conglomerate. This bed, which in the following pages I shall provisionally call the "Bohemia" conglomerate, skirts the northern side of this range near its summit. Above it geologically, on Keweenaw Point proper, no very acid rocks other than conglomerates have thus far been observed,* and it is therefore important as marking the upper limit of the felsites of that district. Above it comparatively few conglomerates occur until we reach the so called Ashbed group above the Greenstone.

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* In the Tamarack and Franklin Junior (Peninsula) mines thin beds of "jasper" have been reported, but no samples from them have been seen by the writer. Marvine's "jasper" bed, No. 6, appears to be of sedimentary origin. See Geol. Sur. Mich., I, Pt. II, table opp. p. 60. *Infra*, Chap. V.

From this horizon upward, conglomerates and sandstones predominate; the Great conglomerate, about 2,200 feet thick[*] at Eagle River, and the Outer conglomerate with the interbedded Lake Shore trap occupy the entire northern rim of the Point. It is foreign to the purposes of this sketch to enter into more minute details concerning the Keweenaw series otherwise than as they affect or are affected by the subject immediately in hand—the felsites or most acid rocks of Keweenaw Point. For further information the reader should consult the accompanying maps, but more particularly the extensive literature on the subject, to which references are given on subsequent pages.

§ 3. Conclusions of previous observers.

The literature relating to the acid rocks of Keweenaw Point is not very extensive. In drawing upon it in the following pages I may in one or two instances digress somewhat from the subject of the felsites, to touch incidentally upon some other subjects that have come under observation during the progress of our field work.

Douglass Houghton: The lower beds of the copper-bearing complex of Keweenaw Point, now known as the Keweenaw series, were by Dr. Houghton, Michigan's first State Geologist, considered as members of a series of metamorphosed rocks which passed gradually from the granite of the iron region into the greenstone and its associated amygdaloid.[†] Dr. Houghton did not attempt to differentiate the felsites from the more basic rocks, but covered both classes of rocks with the generic term "greenstone," applying it not to the amygdaloids but to the more *compact* of the "traps." The term "trap," too, in the usage of that time, and even later,[‡] covered not only the basic rocks of the series but what have since been shown to be the non-sedimentary acid rocks as well.

Overlying these compact and amygdaloidal metamorphosed rocks were (1) a conglomerate, (2) a mixed conglomerate and sandrock, and (3) a red sandstone. The first two which represent Irving's "Great" conglomerate and "Outer" conglomerate respectively, were considered by Dr. Houghton to be in effect one sedimentary* formation, divided by a trap dike, the "Lake Shore" trap of Irving. Indeed, this phenomenon was according to Dr. Houghton not rare, for he alludes to the frequency of "dykes" in the series "of from fifty to four hundred or five hundred feet." To the action of "dykes" protruded between the strata and having with them a common inclination, Dr. Houghton attributed the metamorphism of many of the sedimentary rocks. From the context this statement should seem to refer to the amydaloids,† which in part Dr. Houghton considered due to the fusion of the lower parts of the sedimentary beds. Whether this statement is also meant to cover the felsites does not appear.

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[*] According to Marvine. This may, however, include what I have called the Middle conglomerate. *Infra*, Chap. III.

[†] Third Annual Report, 1841, Mich. Joint Documents, pp. 487, 489. See opinion of Dr. John Locke, in Trans. Am. Phil. Soc., Phil., Apr. 19, 1844, IX, pp. 283-315. Bela Hubbard sees in an "imperfect sienitic granite" of Keweenaw Point (probably a porphyrite) a proof of the "identity of origin of the trap and granite rocks." "Mineral Region of Lake Superior," by J. Houghton, Jr. and T. W. Bristol, 1846, p. 30; also Ann. Mess. and Accomp. Docs., 31st Congress, 1849-50, Pt. III, p. 837.

[‡] Foster & Whitney used the term "trappean" in the same sense, as late as 1850. Report on the Geol. and Topog. of a Portion of the L. S. Land Dist. in the State of Mich., Pt. I, p. 59. Hereafter in the following pages this report will be referred to as F. & W.

U. S. Linear Survey: The geological work of the Linear Survey was begun under the direction of Dr. Houghton, after the publication of his report of 1841. On their maps of Keweenaw Point, which was not subdivided until 1845, the year of Dr. Houghton's death, we find noted the felsite‡ of Bare Hill, in Sec. 29, T. 58, R. 28, and other similar outcrops as "reddish hard trap" and the like.

Bela Hubbard: Bela Hubbard, Assistant State Geologist under Dr. Houghton, and Deputy U. S. Surveyor, speaks of the "trap" of Mt. Houghton,§ and mentions as occurring in the central portions of the South Range of Keweenaw Point, a

> very hard and compact trap of a reddish color, which sometimes takes on the character of a trap-breccia, or aggregate of small cemented angular pieces of rock, and may perhaps be denominated a trap porphyry.‖

In his report for 1845 as Deputy Surveyor, he says:

> Keweenaw point may be said to be made up of three rock formations—trap, trap conglomerate, and red sandrock: of these the first mainly gives its peculiar character to the country, giving to it its mountainous aspect and general configuration, having been protruded by the operation of igneous forces into its present position; while the other rocks are sedimentary in their origin, and are found surrounding and resting against the other;¶

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* *Loc. cit.*, pp. 491, 494.

† *Loc. cit.*, p. 490, See also p. 497.

‡ This is designated as "hard compact reddish trap" and a felsitic conglomerate (or breccia?) as "porphyry trap."

§ Min. Reg. of L. S., 1846, p. 28.

‖ *Loc. cit.*, p. 30.

¶ Ann. Mess. and Accomp. Docs., 31st Congress, 1849-50, Pt. III, p. 836, *et seq.*

and he refers to the trap exposed at Copper Harbor (the "Lake Shore" trap of Irving) as a dike.* On a preceding page (838) he had referred to the lower of the two conglomerates intruded and separated by this trap "dike," as having "been deposited around the base of the trap hills, beneath the waters" and having been subsequently elevated with them. These views agree substantially with those of Dr. Houghton and were evidently formed while Hubbard was acting as assistant to the former.†

During the season of 1846, however, while Hubbard was at work in the Ontonagon-Porcupine Mt. district, his views seem to have undergone a material change. It does not appear that Dr. Houghton ever examined this district in detail. The study of the structure of the Keweenaw series in the Ontonagon district, to which perhaps by reason of the early discovery there of mass copper, more attention was then being given than to the northern parts of Keweenaw Point, led Hubbard to the conclusion that the trap series was probably bedded. He says that the trap range between Portage Lake and the Ontonagon River is but a prolongation of that of Keweenaw Point, and

> bears also a close analogy to the greenstone and amygdaloid of the latter. The high knobs are composed mostly of greenstone which is usually hard and compact. It sometimes approaches a crystalline structure, in which the feldspar and hornblende are aggregated in distinct grains, but generally the constituent parts of the mass are so blended as not to be separately discernible to the eye. This character of rock is, however, far from composing the whole great mass designated as trap, nor does it seem possible to consider the latter as a single dike or contemporaneous uplift; for though the compact variety usually composes the greater part of the cliff, the entire mass will be found to consist of *regularly disposed and alternating beds of greenstone and amygdaloid*, the latter sometimes giving place to epidote. * * * These alternating beds * * * give an appearance of stratification to the mass.
>
> These observations will apply also to that portion of the surveyed district embracing the Porcupine mountains. Associated, however, with the greenstone and amygdaloid of that country, appears an argillaceous and silinous [silicious?] rock, which, though we have classed it among the trap rocks, is very distinguishable from all the other varieties of trap, and is therefore entitled to a separate description. This rock occurs in belts, alternating with those which make up the mass of the Porcupine ranges, and possibly may be regarded as a *volcanic mud*, altered and hardened by its vicinity to rocks of igneous origin.

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* *Loc. cit.*, p. 839.

† *Loc. cit.*, p. 840.

> The arrangement exhibited by these rocks has been alluded to as one of *apparent stratification.* While we desire to avoid any theoretical conclusions as to the mode of their formation, we cannot but observe that the character of the entire trap formation is rather that of a succession of overflows, than of simultaneous uplift in mass; in other words, it may be considered as made up of *beds* of the different kinds superimposed upon each other. It has been already observed that in the Porcupine ranges, the trap, sandstone, and conglomerate beds compose part of these alternations, in deposits of greatly varying thickness. It is difficult to reconcile the frequency of these interpositions, the comparative thicknesses of the beds, and the few signs of disturbance, with the supposition of a protrusion of the trap, as an igneous mass from beneath, through strata of the overlying sedimentary rocks. We would not be understood to assert that no uplift of the trap has taken place, but merely to distinguish between the mode of formation of the several rocks, and the subsequent and general uplift, by which the whole series has been thrown from a horizontal and inclined at the angle at which we now find them.*

It appears from the foregoing that Bela Hubbard was the first to call attention to the bedded nature of the trap series, and to the possible non-sedimentary origin of the acid rocks of that series. Of the latter he says,

> It has been already mentioned, that, alternating with the several rocks that compose the Porcupine mountains is a hard rock of red color, fine grained, and sub-slaty in structure. It is evidently trappose in character, but is at the same time quite argillaceous, and sufficiently siliceous to strike fire under the hammer. Its color varies from a light to a dark brick red. In character and composition it bears a strong resemblance to the cementing portion of the conglomerate rock of the country.*

This rock is evidently the one previously referred to as a "volcanic mud," and from its description it appears to belong in the same group as the felsites.

C. T. Jackson: Dr. Jackson speaks of the sandstone being sometimes

> indurated into a flinty red rock resembling jasper * * * on the coast, Tp. 58, R. 28, Secs. 25 & 26 (25 & 35?), where the jasper-like rock forms bold cliffs projecting into the lake. This rock in some places passes into a distinct porphyry, and appears to have derived its feldspar from the adjacent

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* *Loc. cit.*, pp. 886-887. I have quoted Bela Hubbard at some length, because Irving, both in his "Copper-Bearing Rocks of L. S.", Mon. V, U. S. Geol. Sur., and with Chamberlin in Bulletin No. 23, U. S. Geol. Sur., overlooks this suggestion as to the bedded nature of these rocks, a view, which, it will be observed, Irving adopted not only for the basic rocks, but for the acid rocks as well.

porphyritic trap. In some instances it seems to have been entirely fused and thrown up like a poryhyry dike.*

Since Dr. Jackson appears to have held the broad theory of Houghton that the basic rocks of Keweenaw Point were also of dike origin, this reference to the acid rocks is without special significance.

Speaking of Mt. Houghton, he says:

> The rock at this place is a dull red jasper, stratified in structure, and splitting into thin sheets. It is supposed to be an indurated fine red sandstone, which has undergone partial igneous fusion by the heat of the trap rocks, which are in immediate contact with it.†

Dr. Jackson mentions a "porphyritic trap rock" at the Suffolk location, and another near the same locality, that has red feldspar crystals scattered through it.‡

The highest points of the Porcupine Mountains are by him said to be

> made up entirely of massive quartz rock, or jasper. Its structure and texture vary considerably at different points. The greater portion of it, however, is a homogenous compact jasper of a deep brick red color. The whole appearance of the rock is that of an erupted mass. The jaspery mass is occasionally varied by numerous, delicate, light-colored streaks or bands contorted so as to form an imperfect ribbon jasper. At other points particles of white quartz are mingled with the red jaspery mass. The compact variety of quartz rock sometimes shows a gradual passage into quartzose porphyry, the jaspery mass showing here and there a crystal of feldspar imbedded in it. §

J. D. Whitney, Assistant Geologist under Jackson, described an acid rock in the Porcupine Mountains as follows:

> Found a low bluff on the southern side made up of a compact red jaspery mass, which may, perhaps, be nothing more than sandstone altered by the proximity of the trap. It is exactly similar to that found on Mount Houghton. In some places, even, it still seems to retain distinct marks of stratification; in others it seems to be entirely converted into jasper.‖

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* *Loc. cit.*, pp. 399, 400.
† *Loc. cit.*, p. 414.
‡ *Loc. cit.*, pp. 430, 433.
§ *Loc. cit.*, p. 661.
‖ *Loc. cit.*, p. 728.

Foster and Whitney say of the Bohemian Range:

> The protrusion of so vast a mass of heated matter has changed in a marked degree the associated sedimentary rocks, causing them to resemble igneous products.*

Other references will be noted hereafter.

From the foregoing extracts it will be observed that by Jackson and by Whitney, and by Foster and Whitney the acid rocks of the trap series were looked upon as altered sandstones, except that Jackson, following Bela Hubbard, thought those of the Porcupine Mountains might be of volcanic origin.

Fr. C. L. Koch expressed doubts as to whether the amygdaloid rocks had been produced by the fusion of sandstone and trap, as advocated by Dr. Jackson (and previously by Dr. Houghton), and thought that the jasper-like masses and "jasper-porphyry" of the southeastern part of Keweenaw Point, as well as similar rocks in the Porcupine Mountains, were of a like origin with the traps, i. e., eruptive; that they had come up in a plastic (erweichtem) condition produced by chemical agencies—not in a molten condition—and cited the opinion of Hausmann on the Hartz Mountains. The quartz porphyries southeast of the Porcupine Mountains (Tps. 49 & 50, R. 42), he says, if they are identical with the silicious rocks of the Porcupine Mountains (as Irving admits they are†), must be later than the trap rocks on each side of them, that is to say, intrusive.‡

Thomas MacFarlane observed reddish acid rocks on Michipicoten Island and considered them to be eruptive.§

R. D. Irving, while he was not the first to recognize as eruptive some of the felsites and porphyries of the Keweenaw series, is fairly entitled to his claim of being the first to recognize the fact that *all* of them are "original masses."|| He describes many exposures of acid rocks around the rim of the Lake Superior basin, and while in some cases he admits the difficulty of reducing their structural relations to an "intelligible order," and in others admits that they are

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* F. & W., 1850, Pt. I, p. 64.

† Copper-Bearing Rocks of L. S., 1883, p. 208.

‡ Die Mineral-Regionen der obern Halbinsel Michigan's am Lake Superior und die Isle Royale, 1852, pp. 121, 125.

§ Geol. Survey of Canada, Rept. of Progress, 1863–66, p. 142.

|| *Loc. cit.*, p. 95.

intrusive,[*] he nevertheless concludes that they are in general interbedded flows[†] and were extravasated in the early part of the formation of the Keweenaw series.[‡] He describes acid rocks at the Palisades and at Baptism River in Minnesota, which he says are true layers of quartziferous porphyry between typical diabases and amygdaloids, and asserts that whenever less plain occurrences have been closely studied, it has become evident that in them, too, we have to do merely with interbedded porphyry masses.[§]

In accordance with these views Irving says that the Porcupine Mountains "owe their existence in all probability to a fold, the porphyry of the central portions being one of the usual embedded masses laid bare by subsequent denudation."[||]

Irving's monograph and Irving and Chamberlin's bulletin are among the most complete and elaborate works ever published on Lake Superior geology, and set forth views that not only are ably advocated by those eminent geologists, but have also, in part, found wide acceptance. On the soundness or unsoundness of Irving's views as to the relation of the felsites to the traps, may depend in some measure the correctness of his and Chamberlin's theory of the contact relations between the Keweenaw series and the Potsdam sandstone.

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[*] *Loc. cit.*, pp. 144, 206, 299, 306, 308, 309.

[†] *Loc. cit.*, pp. 91, 145, 150, 240, 299, 435. The term "interbedded" has been used by different writers with different signification. Among the latest of these, Van Hise speaks of "interbedded sills" and of *intrusive* diabase which occurs as "interbedded sheets" (Principles of North American Pre-Cambrian Geology, U. S. G. S., Sixteenth Annual Report, 1896, p. 789). Emmons, however, earlier used the term as applicable only to a surface flow, that was subsequently covered by a later bed (Geology and Mining Industry of Leadville, U. S. G. S., Mon. XII, 1886, p. 295) Irving used the term in the latter sense (*supra.* pp. 149, 299). This usage seems to correspond well with the idea of the deposition of a lava flow—a cover laid down on the top of a pre-existing surface, just as different parts of a sleeping-bed are made up. The term "intercalated" implies *insertion* between parts previously in existence, and to express the idea of "contemporaneousness" is for that reason as objectionable as "interbedded" is for an intrusive. "Interbedded," then, may be considered as equivalent to "interstratified," and applied to *extrusive* sheets, while "intercalated" is a proper term for an *intrusive* sheet.

[‡] *Loc. cit.*, pp. 150, 186, 195, 198, 433.

[§] *Loc. cit.*, pp. 148, 149.

[||] *Loc. cit.*, p. 150.

CHAPTER II

SCHLATTER LAKE AREA

§ 1. A. Definition of field names of rocks.

In the following pages I shall use the term *melaphyre* generically to cover the more basic and augitic effusive rocks, qualifying it by *doleritic* when coarse grained, *ophitic* when lustre mottled, *diabasic* when it discloses lath-shaped feldspars in an augitic matrix, and *amygdaloidal*, when it contains gas-formed cavities either empty or filled with foreign minerals. The term *porphyrite* will be used to designate rocks known to be of medium acidity, whether they carry feldspars visible to the naked eye or not. The word *trap*, commonly used by the miners, is a convenient field term and will include fine grained compact varieties of both melaphyre and porphyrite, where the exact character of the rock has not been determined and more often, perhaps, will be used in a still broader sense, to cover the entire Keweenaw series. The very fine grained and highly acid rocks, formerly also included under the term trap, will be called *felsite*, or when they carry feldspar or quartz crystals in some abundance, *porphyry*. (See Part I, p. 52).

B. Outcrops of acid rocks on Keweenaw Point.

The outcrops of acid rocks observed by the Survey occur in Sec. 30, T. 58, R. 27 (New England or Keystone location); Sec. 25 (?), Sec. 35 (Fish Cove), Secs. 26 and 27 (Little Montreal River), all in T. 58, R. 28; Secs. 29 and 30, T. 58, R. 28 (Bare Hill and westward therefrom); Secs. 23 and 24, T. 58, R. 29 (Mt. Houghton) and both eastward and westward therefrom; Sec. 10, T. 57, R. 31 (Suffolk location, Praysville); Sec. 4, T. 56, R. 32 (Allouez Gap, east of the Kearsarge and Wolverine mines); Sec. 30, T. 56, R. 32 (falls on branch of Trap Rock River); Sec. 36, T. 56, R. 33 (Douglass Houghton Falls), and Sec. 1, T. 55, R. 33 (Hecla and Torch Lake R. R.).

The northern limit of these acid rocks—felsites and porphyries—as far as they were observed and traced, is marked near the end of the Point by the Bohemia conglomerate, as above stated, which is in places quite thick, and is in near proximity to two other thinner and less extended beds of a like nature, all of which ultimately unite to form one bed. Below this conglomerate the felsites occur at different horizons down to the shore of Lake Superior, where in some instances they extend indefinitely beneath the waters of the lake.

The different felsite outcrops will be taken up in detail, as far west as Mt. Houghton, and the area thus comprised will be considered at length before proceeding to other areas further southwest. For convenience this area will be subdivided into the Schlatter Lake and the Bare Hill areas, the former comprising all the territory east of the mouth of the Little Montreal River together with a small part of Sec. 27, T. 58, R. 28, immediately west of the river.*

§ 2. A. Sec. 30, T. 58, R. 27.

The first reference I find in geological literature to acid rocks exposed in this section is by Foster and Whitney, who say, as quoted above:

> The protrusion of so vast a mass of heated matter [Bohemian Range] has changed in a marked degree the associated sedimentary rocks, causing them to resemble igneous products. Thus, on section 30, township 58, range 27, by the lake shore, is seen a metamorphosed sandstone resembling jasper. Its general bearing is east and west. In places it assumes a vesicular appearance, while other portions are brecciated, and take into their composition chlorite and feldspar. In some hard [hand?] specimens the lines of stratification can be recognized. The mass is about 100 feet thick, and surmounted by alternating bands of porphyry and a chlorite rock known as rotten trap, which may be regarded as a volcanic ash. These veins attain a thickness of only a few feet.†

On the shore, at the above named section, where in the early days of copper mining on Keweenaw Point a pit was sunk on what was called the Keystone location (New England?) at a point which according to the plat of the Linear Survey is about 400 to 600 paces west of the east line of Sec. 30, there are several outcrops of felsite covering a belt about 230 paces long, running east and west, and not over 30 paces wide as exposed. These outcrops, all of them in the water or at the water's edge, although to some extent separated, either by the water or by the sand and shingle of the beach, evidently belong together. The most easterly exposures are shown in the accompanying diagram, Figure 1. At the extreme east end a point, A, with an island opposite or south of it, rises about three or four

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* See map, Pl. IV.

† F. & W., p. 64.

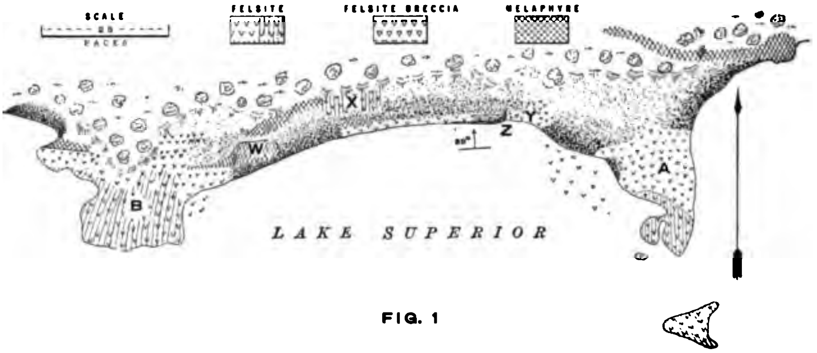

FIG. 1

Exposures of felsite at Keystone or New England location, Sec. 30, T. 58, R. 27, Keweenaw Point, Michigan.

feet above the water. The rock of this point is thinly jointed nearly north and south; that of the island about N. 33° W. The neck of this point where it joins the beach, flattens and is frequently covered by the water of the lake. Here the nature of the rock changes, apparently quite suddenly, and instead of a distinctly jointed, rather fresh-looking rock, we see a rock made up of reddish, light and dark patches of felsite, more or less surrounded by a white kaolinitic material. The latter is evidently the result of decomposition,* for on many of these outcrops the zone of the kaolinitic material is pretty sharply marked and is confined to their lower parts—those that are most subject to the alternating action of the atmosphere and the lake water. I have said that the line of demarcation between the fresh and the decomposed rocks is quite sharp, and yet along this line in places one can see the gradual transition from fresh to decomposed in what was originally one continuous band.

The zone of decomposed rock extends 25 or 30 paces north on the beach and can be seen in the shallow water extending some distance west of the rock, almost visibly connecting with an outcrop at **Y**, 40 paces west. The latter outcrop, level with the beach, holds abundant inclusions of basic rocks and on its north side is flanked by a dark-colored, boulder-like rock, possibly not in place, which is also largely basic. The inclusions in the rock at the water's edge are very distinct, owing to the gray and yellow alteration colors of the matrix. Six paces west a rock, **Z**, 4 feet high and over 4 feet thick rises from the water's edge, contains fragments of foreign rocks, and shows both in the hand specimen and in the thin section (17140) a distinct banding, east and west in the rock, due to flowage. It dips N. 80°, and strikes slightly north of west. It forms part of a wall which on the west falls gradually to the level of the beach and is flanked on the north, at its two extremities, by a thin layer of melaphyre in close contact. It disappears under the sand at its west end opposite a felsite, **X**, like that at **A**, which, like the latter is also thinly jointed north and south, and is more or less shattered. Ten paces further west, at **W**, two melaphyre outcrops separated by sand seem to lie in the way of the westward continuation of the felsite wall, but digging in the sand disclosed between them an east and west slip in line with the felsite wall, dipping like the latter, and carrying some fluccan and chloritized melaphyre.

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* Irving mentions "calcitic" decay of the felsites, *loc. cit.*, pp. 312, 319, and kaolinitic decay, *ibid.*, p. 146.

Up to this point it was not clear whether the fragment-bearing felsite wall with east and west flow lines was a part of the decomposed bed under it, or an independent mass.

For about 6 paces west of the melaphyre at **W** sand and shingle cover the rocks, but at 7 paces west occurs a small exposure of felsite jointed north and south.* Two paces further west is another felsite mass jutting into the lake, at **B**. It is like the felsite at **A**, and its outer or southern part is jointed and banded on the east side nearly north and south; as the west side of the ledge is approached, however, the jointing curves from southwest and west to east. The most northerly part of this ledge shows no distinct jointing, but otherwise closely resembles the southern jointed portion, the rock at each place being spherulitic. The spherulites are generally quite small (1-16 inch in diameter) but in some layers they are over an inch in diameter, and irregular in form. The jointing in these rocks, which is quite conspicuous, seems to coincide with a banding due to the disposition of the spherulites, not like the flow structure of the wall **Z**.

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* In 1896 the rocks were exposed here, showing the eastern extensions of the felsite from B and the westward extension of the melaphyre north of it, to the east edge of B, also the eastward extension of the felsite north of the non-jointed portion—as shown in the diagram.

Near the north part of this ledge, **B**, and on a line with the felsite wall, **Z**, is a fairly well defined zone more than 5 feet thick that cuts off the jointing on the south, and carries fragments of felsite and of melaphyre, especially on the west side of the ledge. At this latter point the zone is in contact on the north with melaphyre. From here for 90 paces west the shore is lined with outcrops of basic rocks, to another ledge of felsite which juts into the lake. It much resembles the rocks at **A** and **B**, is decomposed below the water line, and contains a few small inclusions of dark-colored rocks and several larger ones of felsite, whose banding nearly always coincides with the longer axis of the ledge, east and west. There are many evidences of sliding in this outcrop. At its contact with the melaphyre on the north it contains numerous inclusions of melaphyre and shows an east and west banding, which dips 70° to 80° north. This banded portion is well marked for only three or four feet south of the contact with the melaphyre, but there is no such contact with the felsite south of it, as was observed at **B**.

Between **B** and **C** and in their line of strike several felsite masses rise from the water; and in the lake, a quarter of a mile east of **A**, there is another small island in the same line, the nature of which, however, was not ascertained.

The above facts make it not impossible that we have here two ages of felsitic rocks, the earlier of which appears to have intruded the basic rocks—*if the direction of its jointing is any indication of the direction of the flow*—and possibly to have been itself later intruded by a dike of felsite, which has taken up many fragments both of acid and of basic rocks. Whether this banded zone is simply the margin of the entire felsite mass or a later intrusion may perhaps be left an open question, but the jointing of the felsite, if it has any significance, and the irregular relations of the several felsitic and basic outcrops to one another not satisfactorily explained by fault hypotheses, point to the intrusive nature of the main felsite mass.

The petrographic characters of these rocks were described by Rominger*, who noticed their spherulitic, banded and amygdaloidal structure, and their decomposition to kaolinite. The rock forming this fragmental zone he calls a "coarse breccia, of partly angular, partly rounded, water-worn felsite fragments," a name which evidently does not fully express his meaning, for although he does not differentiate between the different outcrops nor attach any significance to the different jointings, he clearly recognizes in this "breccia" a rock of eruptive origin.

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* Geol. Sur., Mich., V, Pt. I, p. 139.

B. Sec. 30, T. 58, R. 27. Westward.

Following the shore N. 76° W. from the last named locality, we find, about 1000 paces further west, another series of outcrops, also mentioned by Rominger* but not described by him. They are exposed on a narrow beach and are cut off on the east by melaphyre, the fault line apparently running southeasterly into the lake. This is evidently the outcrop described by Foster and Whitney as quoted above.

A curving band of red felsite with an average east and west strike, showing distinct flow lines, and containing lenticular fragments of felsite, which in its lower edge or footwall are very small, is in contact on the north or hanging side with melaphyre. Beneath it is a bed of reddish decomposed felsite, and below this a gray felsitic rock (S.17150).† Next below occurs a reddish rock containing angular fragments and calcite in coarse patches.

This latter bed strikes N. 78° W. and may mark a line of faulting or slipping along the edge of a banded belt filled with broken fragments which comes next under it, and which much resembles in structure a brecciated felsite (S.17149). This banded belt in turn gives place to a bed of amygdaloidal conglomerate under which is a melaphyre, more or less thinly platy and fractured, with some reddish matrix on its hanging, in seams, looking like angular felsitic fragments (S.17148). The west line of section 30, T. 58, R. 27, is probably on or near the east edge of a wide clearing used for banking logs, east of the brook from Hoar's Lake. Between this line and the gray outcrops on the east, just described, i. e. next under the latter, we find a series of melaphyres alternating with at least six melaphyre conglomerates.

The gray and the red rocks strike nearly east and west and amount to about 125 feet in width. Their dip is to the northward, about 70° or more. They show in places distinct flow lines conformable with the direction of their strike, and contain many angular fragments, being in all important respects like the hanging wall portion of the felsite in the same section further east. Like this, too, they are overlain by a compact melaphyre.* The inference appears, therefore, to be justified that we have here a continuation of that felsite, separated by a fault of some 300 paces, the eastern portion being that much further south. This fault will be alluded to later, in connection with the discussion of the Greenstone Range.

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* *Ibid.*

† High numbers preceded by S, in parentheses, refer to thin sections of rocks in the collection of the Geological Survey, by Sp. to the hand specimens.

C. Sec. 25, T. 58, R. 28.

Following the shore south of west from the west line of Sec. 30, we find a continuation downward of traps and conglomerates, most of the latter being of the melaphyre or amygdaloidal variety, with, however, lower down in the series, some beds that contain also rounded pebbles of an acid rock. The first of these latter is about 1135 paces west of the east line of Sec. 25, T. 58, R. 28, or near the north and south center line of the section. It is made up of one foot of rounded amygdaloidal fragments in a calcitic matrix, above a three-foot layer of coarse sub-angular porphyritic pebbles in an abundant sandstone matrix, this in turn succeeded by five or six feet of rounded amygdaloidal fragments in a red matrix. About 90 paces further west we find, overlain by a mottled melaphyre, another conglomerate 5 feet thick, carrying rounded pebbles of melaphyre and fewer of an acid rock. The bed just below this conglomerate gave a strike of about N. 85° W. and a dip of 56° N. Near this point there is also exposed a series of rocks, more or less decomposed and red, containing laumonite, calcite and possibly some other zeolitic mineral, which alternate with fresher and more homogeneous rocks. Unless one of these beds be the brecciated felsite belt referred to by Rominger,† I did not see or did not recognize the latter.

Between the last point and the west line of Sec. 36, T. 58, R. 28, several conglomerates of varying thickness, and largely of basic material, occur interbedded with traps. One of the latter, a fine grained rock, shows distinct columnar structure. The thickest of the melaphyre conglomerates is 50 feet wide and is just south of the north line of Sec. 36.

§ 3. Secs. 26 and 35, T. 58, R. 28. Fish Cove Knob.

Of the next two felsite outcrops met as one goes west along the shore, one lies partly in Sec. 35 and partly in Sec. 26, T. 58, R.

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* No dips were observed in the overlying melaphyre at either of the above localities.

† *Loc. cit.*, p. 139. The beach sand and gravels shift from year to year, covering some outcrops and exposing others.

28; the other wholly in the latter section. These outcrops flank a small bay known in early geological literature as "Fish Cove," and for convenience the larger outcrop on the east side of the bay will in the following pages be referred to as "Fish Cove Knob." Dr. Jackson speaks of it as a sandstone "indurated into a flinty red rock resembling jasper," in T. 58, R. 28, Secs. 25 (35?) and 26.* J. W. Foster refers to it as a "red jasper,"† and Foster and Whitney as a "metamorphosed rock."‡ Rominger speaks of the smaller and more westerly of these two exposures as "a large isolated outcrop of felsitic rock masses," that "projects in high cliffs at the shore." This outcrop consists of two narrow ledges about 8 feet high, jutting into the water, but together being not more than 25 paces long, as exposed, nearly north and south. On the west they are in close proximity to the trap. They flank the west end of a beach about 350 paces long, thickly strewn with felsite pebbles. At the east end of the beach rises the other felsite mass, Fish Cove Knob, which is really an aggregate of several knobs of different sizes and altitudes. They are described by Rominger as a "belt" 500 feet thick, overlain on the north by a belt of porphyritic diabase.§ The limits of this felsite and of the group of knobs of which it forms a part, are shown on Plate I. The shore east of it, as far as the point on the line between Secs. 35 and 26, is lined with outcrops of the coarse grained diabase porphyrite described by Rominger,§ overlain by a fine grained almost aphanitic porphyrite, possibly the top of the coarse bed (S.16972), resembling in the hand specimen in places a very dark felsite, and containing some minute amygdules. In the thin section it shows large oligoclase crystals with some iddingsite [Lane] and magnetite in a very fine feltlike groundmass, and resembles a rock from Michipicoten Island described by Irving.‖

The strike of this latter bed at this point is N. 72° W., which is in close agreement with the prevailing strike higher in the formation, in Secs. 26 and 27 of the same township. Where it approaches the east end of the aforesaid felsite knob, the bed of coarse diabase porphyrite that lines the shore is covered by a beach terrace, but this bed, or a similar one, appears on the east face of the knob, where the well defined contact between felsite and porphyrite strikes N. 57° —60° W. The hanging side of the porphyrite, however, strikes N. 70° W., and the bed soon tapers out against the felsite wall on the west. Immediately above the coarse porphyrite at this point is the fine grained porphyrite already noted in an outcrop further east; it dips northerly 70° and carries some copper. A thin bed of conglomerate, also seen on the point further east, overlies the latter porphyrite. From the western termination of the above beds the felsite, turning abruptly, runs about N. 10° E. and N. 30° W. for nearly 200 paces, its immediate contact with the basic rocks being covered by drift. Fifty paces east, however, on the adjacent knob a thick bed of doleritic melaphyre is exposed in the upward continuation of the series. It seems quite evident, therefore, that the felsite cuts off the bedded rocks. The wedgelike termination of the coarse diabase porphyrite and the absence of any marked disturbance in the overlying beds, so far as observed, might possibly be looked upon as the natural result of a series of flows around the flanks of an earlier extrusive mass, but on this hypothesis we cannot well account for the east-facing cliff unless there was a considerable cutting away of the base of the felsite during the formation of the abutting beds, and that this was not the case is made probable by the rarity,—in fact, entire absence,—so far as observed, of felsitic conglomerates at this horizon. The dip of the fine grained porphyrite noted above (N. 70°) which is 16° steeper than the prevailing dip of the beds in the interior of Sec. 26 on the north, is also significant.

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* Ann. Mess. and Exec. Doc., 31st Congress, 1849-50, pp. 399, 400.

† *Loc. cit.*, p. 767.

‡ F. & W., p. 65.

§ Geol. Sur. Mich., V, Pt. I, p. 138.

‖ Copper-Bearing Rocks of L. S., Pl. X, Fig. 2.

Along the shore the felsite appears roughly columnar, and is also in a general way jointed parallel with the strike of the bedded rocks, the joints dipping like the latter to the north. It is also slightly brecciated near the east end of Fish Cove beach.

§ 4. Secs. 26 and 27, T. 58, R. 28. Interior.

A. General description.

The ground for 350 paces north of the beach between the last two mentioned felsite outcrops is low, flat, sandy and forest-covered. Beyond that limit, however, for nearly a mile east and west, is the burnt area above mentioned, that extends across parts of Secs. 26 and 27.

The surface of this tract is very uneven, being broken into a succession of short ridges and knobs which rise to a height of 150 to 180 feet above Lake Superior. These are separated by narrow valleys, in some of which vegetation was not affected by the fires. The ridges and knobs, however, many of them, are almost bare, even of soil, and the different rocks that compose them can, in some cases, be followed uninterruptedly for long distances. (See Pl. II.)

B. Cross-section in Sec. 27, T. 58, R. 28.

In order better to understand the relations of the rocks that occur beneath the most northerly felsites of these two sections and the disturbances that have taken place there, it may be well to introduce here a cross-section (Pl. III) and brief descriptions of the principal beds.

Following up the Little Montreal River from its mouth, where it falls over slightly corraded trap beds* about 25 feet above the lake, we soon reach a pool where the river bed makes a sharp turn to the east (Pl. II). Between this point and the lake shore the surface is more or less drift-covered, and was not examined in detail; it was seen to be underlain by lustre mottled melaphyres, or ophites, and melaphyre conglomerates, and by at least one small conglomerate that carries rounded pebbles of a more acid rock. The cross-section runs north from the pool at 50 paces S., 400 paces W., of the E. quarter-post of Sec. 27. (R—S, Pl. II.)

1. Basic eruptives. Beginning at the south end of the cross-section at the lowest or oldest part of the formation, we find on the south or left bank of the river a bed of coarse ophite, **A**, much altered, and peculiarly banded. This bed, as we shall see, plays an important part in our subsequent correlation. Above it, in the river bed is an amygdaloidal conglomerate which is overlain by a melaphyre and, succeeding these, are other sheets of similar basic eruptive and fragmental rocks. The original or eruptive rocks in the series occur in beds from 10 to 140 feet wide, or from 8 to 112 feet thick, four of them being upwards of 55 feet thick, and each bed varies more or less in width from place to place. As a rule they are compact and homogeneous, but many of them carry rounded or lenticular amygdules of quartz or of agate in sufficient quantities to be quite noticeable, but not always to form a typical amygdaloidal structure. This character in beds of the lower-middle part of the Keweenaw series has been noticed at many

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* Well marked glacial striae were found in the river bed here.

points between the Little Montreal River and the Portage Lake area.*

The compact melaphyre beds exposed along the middle parts of our line of section are in general narrow. No attempt was made to trace these beds in detail on the west side of the river, or to determine the amount and direction of the faults which are supposed to cross them, but which are probably of less magnitude and frequency than those found on the east side. Indeed, the narrowness of some of the beds and the amount of drift in places, would probably render such an attempt fruitless. Between beds **A** and **E** no absolute correlation was established with beds further east. **B, C** and **D** denote simply horizons that correspond approximately.

2. Basic conglomerates. A marked feature of most of these melaphyres (below an acid zone soon to be considered), is that the amygdaloidal portion or top of the flow no longer forms an integral part of its underlying bed, but has in most cases been broken up into a breccia-conglomerate with a reddish matrix. For over 200 paces immediately above the crowning acid conglomerate in this area basic conglomerates were not noticed. Within a like distance lower in the series, however, there are at least six of them if not more. Indeed it is the exception to find a compact melaphyre without its capping, more or less scoriaceous, conglomerate. This, in connection with the width of some of these detrital beds should seem to indicate that the earlier beds were formed at longer intervals than occurred between the outpouring of the beds above the acid zone, or that the beds above the acid zone were not submerged. It is characteristic of these conglomerates that they contain no acid pebbles such as are found in the better known conglomerates of Portage Lake. Roughly rounded to sub-angular fragments of amygdaloidal rock lie imbedded in a copious cement of a fine reddish material which consists of a mixture of quartz grains and of both basic and acid rock fragments. In color this cement is in marked contrast with the pebbles, which have a bluish green cast, possibly from the presence of salts of cop-

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* "It must be expected that currents of lava which have flowed at great depths under water, will present comparatively few scoriform parts. * * * Vesicles or air-bubbles, on the contrary, should be expected to abound in the interior of the rock, whenever its liquidity was sufficient to permit the agglomeration of the vapor into parcels; the extreme tension of the elastic fluid causing the expansion of the bubbles as the lava flows on; while, for the reason mentioned above, very few will make their escape by rising outwardly." Scrope Considerations on Volcanos, London, 1825, p. 177.

per, and this matrix often stands out on an exposed surface, like the pointing in a wall of masonry. Figure 2 from a photograph of bed F shows well its character. In the figure the handle of the hammer is a foot long. It is quite noticeable that the line of demarcation between these conglomerates and the underlying parent bed—melaphyre—seldom exhibits the characteristics of an eroded surface.

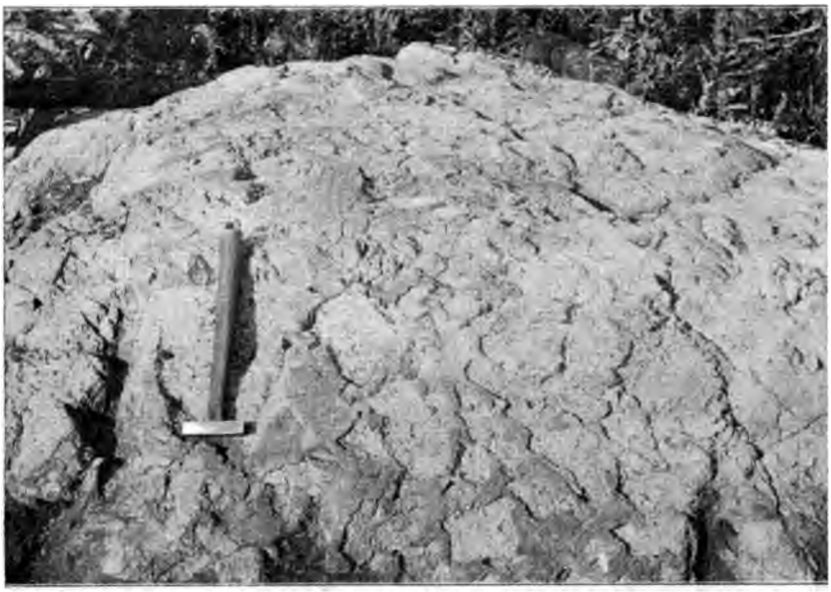

Fig. 2.—Melaphyre conglomerate.

Irving has described three types of conglomerate of diabase and diabase-amygdaloid:

> one in which the pebbles are distinctly waterworn, and another in which there is no such distinct evidence of water action, and in which the vesicular exteriors of the balls suggest their possible origin as volcanic scoriae that have become buried in the accumulating detritus. The first of these varieties has been noted on the North or Minnesota shore only. The other has been observed on both the South and North shores, and is often hard to distinguish from a kind in which the red shaly material is most confusedly mingled with the vesicular amygdaloidal diabase, which at times seems to grade into the detrital matrix, and again to be separated from it in more or less distinctly defined balls; an appearance suggesting the deposition of detrital material upon and within the extremely scoriaceous upper portion of a lava flow.*

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* Copper-Bearing Rocks of L. S., 1883, pp. 29, 30.

The peculiar type of amygdaloid characterizing the so-called Ashbed of Keweenaw Point * * * appears as a peculiar and irregular mixture of red sand and amygdaloidal material, and bears at first sight some resemblance to those conglomerates already described, in which the pebbles are amygdaloidal. But in the Ashbed the apparent pebbles appear on close observation to be mostly connected, and I am disposed to follow Wadsworth (Notes on the Iron and Copper District of Lake Superior, p. 112) in considering that it represents a very scoriaceous and open layer, upon and within which more or less sand was subsequently deposited.*

The basic conglomerates under consideration belong probably to the second and third classes. Their separation is at times difficult, for the same bed near its hanging and near its foot may have the characters of the two classes respectively. They occur from 5 to 50 feet thick, which fact alone, so far as the thickest beds are concerned, should seem to lend probability to the foregoing supposition; in some of the thinner ones, too, it is hard to determine whether we have before us a true conglomerate or a scoriaceous breccia bed with sand. They vary somewhat in width, from point to point, less so, perhaps, than do the original beds associated with them, and it is very noticeable but not strange that, corresponding to a conglomerate at one point, we find in apparently the same horizon elsewhere two thin beds, conglomerate and melaphyre, amounting to the width of the former, or we appear to find one thick bed of melaphyre corresponding to a series of alternate melaphyres and conglomerates. Indeed, the thinner beds in Sec. 27, below bed **E**, cannot satisfactorily be correlated off hand with beds in Sec. 26, unless we assume either that more flows spread over the former area than over the latter, or that disturbances known to have occurred in the latter area have obscured the relations between the two. These scoriaceous melaphyres and conglomerates were not subjected to a more critical examination by the Survey.†

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* *Loc. cit.*, p. 138.

† An amygdaloidal bed is generally considered as a part of the underlying trap, but since the under side of a trap bed may also be amygdaloidal, two amygdaloids of different ages may thus occur together, apparently as one bed. Scrope ascribes the fragmentary scoriae on the lower side of a lava bed to a breaking up and rolling over on itself of the consolidated top of the flow. This, he says, is possible only in very liquid (i. e. basic) lavas, for all liquids of great viscosity move down an inclined plane *en masse*, "the component particles retaining almost completely their relative positions, without rolling over one another in that free and voluble manner which characterises the motion of more perfectly liquid bodies." This gives rise to the so-called flow-structure, more often noticed in acid rocks; "the crystalline particles of lava move against one another rather as a sliding or slipping of their plane surfaces over each other." *Loc. cit.*, pp. 102, 103. See, also, B. K. Emerson, Diabase Pitchstone and Mud Enclosures of the Triassic Trap of New England, Bull. Geol. Soc. Am., 1897, VIII, p. 64.

Immediately overlying the principal conglomerate bed, **M**, of the acid zone in the higher part of our cross-section, a melaphyre, **N**, occurs which shows, at several points in Secs. 26 and 27, small patches of sandstone on its upper side, and in the former section (1466 paces N., 1786 paces W.) the same bed shows a number of seams that run from the hanging towards the foot, also filled with sandstone. These phenomena indicate the extrusive nature of this melaphyre. Marvine has described a similar occurrence at Eagle River.[*]

3. Acid rocks. Beginning with bed **E**, we meet a group of rocks that deserve more than passing notice, for they constitute a horizon easily recognized and of great persistence, which ultimately forms the backbone of the Bohemian Range to the western end of the latter in T. 57, R. 31. As previously stated, their northern edge, a conglomerate, marks, so far as observed, the upper limit of the original felsites of this area. This is evidently the belt represented on the map of Stevens, Hill and Williams,[†] as "Belt of Jasper," "Highly metamorphosed sandstone and conglomerate," and on Irving's map as "Quartz-porphyry and Felsite."[‡]

Bed **E**, the lowest in this belt, is about 60 paces wide where it crosses the line of our cross-section, and is traceable to the eastern limit of the map (Pl. II), and in the other direction is found in frequent outcrops as far as the western limits of the range. In general this rock is of a dark reddish brown color, weathering to reddish gray. It shows very minute, almost hairlike, feldspar laths in great abundance in a very fine groundmass. Its fracture is irregular, inclining to sub-conchoidal, and so tough and tenacious is the rock that in many places it is exceedingly hard to break. It is because of this quality that this bed has so successfully resisted erosion and now occupies some of the highest elevations on Keweenaw Point. It and a lustre mottled melaphyre, or ophite, apparently in the same horizon as bed **A**, previously mentioned (page 20), appear to have been the main protecting bulwarks of the Bohemian Range. The microscope brings out well in the thin section (S.17000; 940 paces N., 1000 paces W., Sec. 28, T. 58, R. 28) the minute, almost microlitic lath shaped feldspars, among which appear some larger ones not so idiomorphic. The feldspars are all more or less pierced with sericite leaflets, and the section is dotted with epidote and iron oxide. Flow structure is quite noticeable in some sections made from rocks in the same horizon.

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[*] Geol. Sur. Mich., I, Pt. II, p. 119. Cf. Irving, *loc. cit.*, pp. 139, 292.

[†] Geol. Map of the Trap Range of Keweenaw Point, L. S., Phila., 1863.

[‡] *Loc. cit.*, Pl. XVII.

An analysis of this rock (Sp. 17033, from near the hanging, 1098 paces N., 1685 paces W., Sec. 26, T. 58, R. 28) by F. P. Burrall, M. E., gave the following results:—

SiO_2	52.83
Al_2O_3	16.30
Fe_2O_3	9.60
FeO	2.48
CaO	2.98
Mn_3O_4	trace
MgO	3.98
K_2O	2.49
Na_2O	6.54
H_2O	2.76
	99.96

"It fused over Bunsen blast lamp (about 900° C.) to a very dark brown glass. Apparently about as fusible as No. 17039".

This is therefore one of Irving's diabase-porphyrites.* The hand specimen analyzed showed one or two feldspar phenocrysts about ¼ inch long, an occurrence rare in this bed, but common in the felsite porphyrite soon to be described.

Overlying the preceding is a conglomerate, bed **F**, easily traceable. It outwardly resembles most of the other fragmental beds in this area, being composed largely of reddish gray, more or less scoriaceous and amygdaloidal, subangular fragments, in a reddish matrix of fine material. It is the bed represented in Figure 2.

Next in ascending order is a rock, bed **G**, whose outward character corresponds to that of a rock from this locality described by Rominger as a

> very fine grained, dark purplish brown colored, hard but very brittle rock, which under the microscope shows the structure of the so called Ashbed diabase; its irregular splintery cleavage makes it somewhat resemble very dark colored specimens of a felsitic rock.†

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* *Loc. cit.*, p. 77.

† Geol. Sur. Mich., V, Pt. I, p. 137.

This rock differs from the porphyrite of bed **E**, in having an exceedingly fine granular texture visible under a pocket lens. It carries a few scattered feldspar phenocrysts $\frac{1}{8}$ inch long or more, but few or none of the minute feldspar laths seen in the former. It is much more brittle than the diabase porphyrite and while it has an irregular fracture, under the hammer it breaks readily into small angular blocks. Its principal joint planes are generally parallel with the local strike and dip of the formation, which in the area under consideration are about N. 72° W. and 54° N., respectively. These joint planes are frequently not more than an inch apart. Aside from its darker color, it differs from the usual felsite of this region in not showing microscopically on weathered surfaces any flow structure.

Under the microscope (S. 17039) a fine grained groundmass of andesitic feldspar in patches, in general without definable form, but sometimes roughly lath shaped, is sprinkled thickly with fine black patches of iron oxide, and red-stained blotches of epidote. The number of feldspar laths is variable in different sections, though never as abundant as those that characterize the porphyrite, and this seems also to differentiate it from the Ashbed diabase, to which Rominger likened it. Possibly Rominger's specimen came from the next lower bed.

Analyses by Mr. Burrall, of specimens of this rock (Sp. 17039; 1340 paces N., 360 paces W., Sec. 27, T. 58, R. 28; Sp. 17007; 915 paces N., 1060 paces W., Sec. 20, T. 58, R. 28) gave the following results:—

	No. 17039.	No. 17007.
SiO_2	59.52	57.45
Al_2O_3	15.58	15.75
Fe_2O_3	7.24	11.12
FeO	1.86	1.74
CaO	1.81	0.12
MgO	2.11	1.94
K_2O	3.48	3.51
Na_2O	6.82	7.84
H_2O	2.23	1.23
	100.65	100.70

No. 17039 "at 900° C. fused to a dark brown globule;" No. 17007 "at 900° C. melted to a very dark brown glassy globule. Not quite as fusible as No. 17039."

In S.17007 the feldspar seems to be near albite and is more porphyritic than in S.17039. [Lane.]

Chemically this rock belongs in the porphyrite group, being high in silica, very high in iron and low in lime and magnesia, but its structure and fineness of grain are such that it cannot strictly be classed with the diabase porphyrites. All things considered, it may be regarded as a middle form between the porphyrites and the felsites or porphyries, and in the following pages will be referred to as a felsite porphyrite. It is probably one of Irving's quartzless porphyries.*

Next above the felsite porphyrite is a bed of conglomerate, **H**, which towards the hanging changes gradually into a fine breccia, the latter forming about one-fourth of the total width. The larger fragments in the conglomerate, derived principally from the underlying felsite porphyrite, are more or less angular and the lower part of the bed contains a good deal of the red matrix common to the basic conglomerates heretofore described.

Apparently in contact with the breccia on its north side, 40 paces from the hanging of the felsite porphyrite, appears a small outcrop of felsite, **J**, in the bottom of the ravine on the south bank of the brook. This rock is of a pinkish gray color, in whose fine grained to aphanitic groundmass there appears, here and there, a feldspar phenocryst less than $\frac{1}{8}$ inch in length.

Under the microscope this rock (S. 17036A) shows a fine mosaic of feldspar and quartz, with a few small roughly lath shaped phenocrysts of feldspar, both orthoclase and plagioclase. Iron oxide is rather abundant in small dots and apparently also as a stain. The section also shows irregular patches of a slightly darker color and finer grain. These patches seem to be largely non-polarizing, and may represent early cooled and partly devitrified portions of felsite magma.

The structure of this rock and that of the porphyrite, so far as the feldspar is concerned, are thus seen to form two extremes, with the felsite porphyrite between the two, sometimes nearer the felsite, and sometimes more like the porphyrite, with the addition of free quartz (Cf. S. 17007).

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* The Praysville porphyry described by Irving (*loc. cit.*, p. 176) contains 59.52% of silica, but is much more porphyritic.

An analysis of this rock, (S. 17036A, 1440 paces N., 430 paces W., Sec. 27, T. 58, R. 28) by Mr. Burrall, gave the following results:—

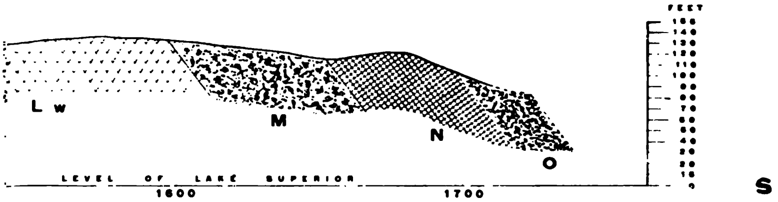
SiO_2	75.67
Al_2O_3	12.43
Fe_2O_3	2.27
FeO	0.15
CaO	trace
MnO	trace
MgO	0.00
K_2O	6.73
Na_2O	2.01
H_2O	0.41
	99.67

"At 900° C. did" (not?) "fuse, but caked and lost its color."

On the north side of the brook, along the line of our cross-section, drift covers the surface for 40 or 50 paces, but 100 paces further east we find outcrops of fine breccia like the bed just south of the last felsite, this breccia, like the other, also forming the hanging of a conglomerate bed which is well exposed near the river in a ledge, **K**, about 70 paces long by 20 paces wide. It is noteworthy, that this conglomerate, in places quite coarse, shows its finest breccia near its contact with a tongue of felsite supposed to connect with the large lens of the same rock, **L**, further west. Under the microscope the breccia (S. 17037) shows very angular and mostly quite small fragments of porphyrite and of felsite or felsite porphyrite material and one well defined crystal of feldspar in a very fine groundmass, apparently sedimentary. It also encloses some ophitic fragments.

Along the line of cross-section, the felsite lens, **I**, is over 100 paces wide; and is overlain by a heavy felsitic conglomerate, **M**, which in some places attains a width of 240 paces. This bed and a thinner one, **O**, of very similar material north of it, are separated by a belt of basic rocks, **N**, nearly 50 paces wide, which in one place appears to consist of only one bed, and in another of several.

The three conglomerates just mentioned eventually merge into one bed (see Fig. 3). For 200 paces north of the uppermost conglomerate, **O**, beds of trap and amygdaloid were the only rocks noted.



8 N., R. 28 W. (400 PACES W.)

The consideration of this zone of acid rocks will be resumed later. Enough has now been said to enable us to take up more in detail the felsites in the interior of Secs. 26 and 27, and to discuss the general relations of the rocks in that area. For this purpose it will be more convenient to begin with the higher beds.

C. Structure.

1. Bohemia conglomerate. The triple conglomerate complex, which I have provisionally called the Bohemia conglomerate, is exposed on the east side of the Little Montreal River in the same relationship to other rocks as on the west side—a thin upper bed, **O**, underlain by melaphyre, **N**, a second thick bed, **M**, underlain by a thin tongue of felsite, **L**, well exposed at the foot of the upper falls, and a third bed, **K**, whose contact with its underlying rocks is not exposed. The conglomerate bed, **O**, is exposed here at three points, on an east and west line, in what appears once to have been a continuous ridge, separated from the main conglomerate on the south by a narrow valley in which lies the melaphyre **N**. The latter bed is not exposed at the most easterly outcrop of conglomerate, but the topographic conditions here are identical with those in the same horizon at the other two outcrops and the melaphyre probably lies buried here under the drift. The strike of the upper conglomerate at the middle outcrop is N. 80°-85° W., and here and at the western outcrop there are off-sets along fissures that strike N. W. and S. E., the more easterly parts of the bed being the further north.

The middle or main conglomerate bed, **M**, near the Little Montreal is seen (Pl. II) to rest on a thin bed of felsite which is probably a continuation of the lens, **Lw**, on the west side of the river. This conglomerate and the lowest bed, for aught one can see, may or may not unite east of the felsite tongue and rest against the sides of the felsite **Le**. The main conglomerate bed along its northern declivity shows several offsets in the same sense as those noted in the upper bed, and its pebbles are much fractured.

2. Felsite lens, Little Montreal River. The felsite **Le**, on which rests the middle conglomerate bed, is a prominent outcrop well exposed for half a mile and traceable to the east line of Sec. 26, beyond which point a thick layer of coarse gray sand, together with the gradual flattening of the land, effectually conceals it. This massive outcrop, at one point 200 paces wide, consists of three roughly oval knobs, from 150 to 175 feet above lake level—the highest land

in the section. It strikes nearly east and west, and its position and trend are such that it is probably in about the same horizon as one of the felsite outcrops in Sec. 30, T. 58, R. 27.

This rock is similar in appearance and character to the other felsites of this area, including the occurrence at Fish Cove, but, unlike the latter, it does not show a columnar structure. At several points along its south side it is brecciated and carries inclusions of basic rocks (Ss. 17225, 17197). It seems to be in contact on the south with a conglomerate or breccia like those above and beneath the bed **J**, on the west side of the river. Some north and south fractures are noticeable in this lens, and one fact that appears to have some significance is the relative trend of the three principal knobs into which the exposed part of the lens is divided. The axes of the east and west knobs trend nearly east and west, while that of the middle knob trends more northwesterly and southeasterly. The western knob slopes rapidly to the west down to level ground, where for several hundred paces in the same direction no rock exposures occur. That it is connected with the thin bed of felsite, **J**, on the west side of the river, and not with the lens **Lw** by means of the tongue of felsite between the main and lowest conglomerates at the upper falls, at one time seemed probable, but the occurrence of the felsite **Je** with an overlying conglomerate immediately beneath the lens **Le**, near the north and south center line of Sec. 26, seems to mark **Je** and **J** as parts of the same bed.

In the last sentence I have taken for granted the extrusive nature of the felsite. In the absence of evidence to the contrary I must regard both the west and east felsite lenses as a flow. Their relations to the surrounding rocks are such as to satisfy this hypothesis; the mere fact of their being overlain by a heavy bed of felsitic conglomerate might alone justify it.

Briefly reviewing the facts above set forth, we find the earliest flows of the Keweenaw series in this area to consist of a succession of basic lavas, each of which, possibly with a few exceptions, passes gradually upwards into, or is capped by, a bed of more or less scoriaceous angular fragments of similar material mixed with sand. The frequency and character of these beds, and the fact made evident by the Bohemia conglomerate that there was here an ancient basin filled with water, make it highly probable that the early lava streams flowed into or under water. Their surfaces, thus suddenly cooled were cracked and broken up, and if they were at some depth below water level the resulting fragments were less subject to the rounding action characteristic of those of most shore-formed conglomerates. That they were at some distance below the surface of the water is possible, not only from their distance below the Bohemia conglomerate, but also from the amount of sand deposited between the fragments, and the general absence from them of foreign material of greater size, although these features in a sedimentary bed might point to formation in a shallow protected bay.

As we ascend in the series a change appears in the chemical nature of the beds. They are seen to be progressively more acid until we find near the top a rhyolite—the felsite—occupying prominent positions near the center of the basin and filling a large part of it. With the upbuilding of the series and the attendant increasing shallowness of the water the formation of a pebble conglomerate became possible and continued, perhaps, until the level of the basin was raised to that of adjacent areas. Just how widespread was this marked sequence from basic to acid rocks is not yet determinable. That it extended some distance west of the area in question is positively known. That it may not be common to the whole Lake Superior region should not surprise us, when we reflect that the lavas of the series probably came from widely separated vents, and were to some extent guided in their course towards the lower part of the Lake Superior basin by the contours of the surface over which they flowed; that probably not many of the beds, if, indeed, any one of them, spread out over the entire Keweenawan area, and that many of them probably solidified without even reaching the bottom of the basin. The sequence of beds at any one point might not therefore be an exact index of all the chemical changes that had taken place even in one volcanic focus during the period in which the beds in a small area were being extravasated. Any argument based on sequence of beds in the Keweenaw series, either for or against the theory of Von Richthoven, ought, therefore, to be made with reserve.

3. West Pond felsite. Between 300 and 400 paces south of the felsite **Lb**, a broken ridge runs about 300 paces easterly from the southeast edge of West Pond. It is made up principally of a coarse grained ophite, much altered [serpentine? Lane] and peculiarly banded in the direction of its strike.

This rock very closely resembles that of bed **A**, previously noted, and that the two belong together appears probable from the following considerations. The horizontal width of the former bed is markedly greater than that of any other melaphyre (the width of the other bed was not measured) in the area under discussion. Its dip, measured on the planes of its bandings, is 80° N., which makes its actual thickness even greater in proportion, the prevailing dip west and northwest being but 54°. Except bed **A**, no other rock has been observed in the area covered by the map (Pl. II) that corresponds to this ophite. That this belt within the limits just stated cannot be regarded as an isolated occurrence, is evident from its great comparative thickness and short lateral extent, such occurrences not having been noted among the basic rocks of the Keweenaw series. That it should be out of line of the similar bed on the south side of the river is probably due to faulting, by which it and the beds north of it have apparently been crowded into a space narrower by one-third than the corresponding zone further west.

Outcrops of felsite flank this ophite belt both on the east and on the west, apparently uniting south of it. On the east side the felsite, P_1, outcrops a few paces west of East Pond, there underlying a melaphyre and partially filling an embayment that runs north along the east side of the ophite. On the west the felsite, **P**, extends 200 paces north along the east shore of West Pond, almost if not quite to the north end of the latter where in a low valley that runs north the rocks are covered. On each side of the valley, however, the structure is well enough exposed to mark the presence of a fault that strikes nearly north and south, or in continuation of the general trend of the felsite mass last mentioned. The porphyrite, **E**, its overlying conglomerate and the felsite porphyrite, **G**, on the east side of the fault are thrown north some 60 paces or more. This appears to be the maximum measure of faulting in this particular zone and is the only case observed excepting at the upper falls, where the direction of the faulting is nearly north and south. Indeed, the fault here may be of a compound nature, the bed **F** appearing to have been thrust northeast past a part of its overlying bed **G**. In Sec. 26 at least a dozen faults were noted, the majority of which run east of north and the others west of north. The irregular course of the bed **F**, in the western part of the section, points to several faults of the former nature. a conclusion that seems to be verified by an examination of the lower beds. It was east of the principal fault, however, that the evidences of disturbance were strongest and most frequent. In an area about 500 paces square immediately south of the great felsite lens $\mathbf{L_E}$, at least eight faults were distinctly traceable, and although outcrops were located only by pacing, it is believed that the different beds were correlated with sufficient approximation to render the work correct as a whole, if not altogether in detail. Some difficulty was experienced from the occurrence of patches of basic conglomerate within what was supposed to be one bed of compact melaphyre. In other cases the thinner interbedded sheet was a compact melaphyre, those on each side of it, conglomerate. Bed **E** belongs under the former head, bed **F** under the latter. A detailed description of these beds is deemed unnecessary. They can be followed by reference to the map, Plate II.

The most noticeable feature of this area is the broken condition of the higher beds. The more basic rocks, except where faulted or jointed, appear in general quite compact. As we go up in the series, however, and reach the more acid rocks, we find the latter in many places so broken by shearing as often to be almost indistinguishable from conglomerates. The angularity of the fragments and their close resemblance to the material of the seams serves, however, to determine their brecciated nature. In places this brecciation seems to have affected only the lower, or only the upper parts of a bed; in others the entire bed is shattered. Again the brecciation is most noticeable along the fault lines.

The marked disturbance of the beds in the immediate area of the West Pond felsite, **P**, their apparent greater regularity as they recede from that area, and the relation of this felsite to the adjoining beds find their most rational interpretation in the intrusive nature of the felsite. The latter appears to have lifted the former, broken them into segments, and during the process to have converted the more brittle of them into typical breccias. This lifting of the overlying beds has also tilted them, so that their dips are steeper there than elsewhere. On the west side of the river and at the upper falls the dip, as previously noted, is 54° to the north. The ophite, **A**, dips 80° and at several points, further north, vertical dips were observed.

In fact the bed **F** shows overturned dips of 80° (to the south). This increase of dips thus accounts for the horizontal narrowing of the disturbed zone and the northerly position of the bed **A**.

The relative age of the intrusion seems also to be apparent. It will be seen by reference to the map, Plate II, that a small embayment in low ground south of the felsite, **Le**, affords space for the westward extension of the bed **G** to the line of the principal fault. This fact and the phenomena already noted in the felsite and overlying beds to the north—direction of axis of middle felsite knob, fracture of conglomerate pebbles, offsets in the conglomerate beds, easterly strike of upper conglomerate—are in harmony, not with the hypothesis that the felsite, **Le**, was laid down unconformably on the upturned edges of the underlying beds, but that the felsite and overlying conglomerates shared the disturbance caused by the intrusion of the West Pond felsite, and that the age of the latter was later than that of the Bohemia conglomerate. How much later this disturbance occurred no facts are at hand to determine.

The West Pond felsite, **P**, on a fresh fracture surface is of a terra cotta color, very compact and aphanitic. It resembles in all important respects the felsites previously noted. In the burnt area they all weather white and their debris is abundantly scattered over the surface in small sharply angular fragments. Spherulites occur near West Pond to the size of an inch in diameter. At several points the margin of this mass is lined with a band of rather fine breccia, like that of beds **H** and **K** previously noted.

What appears to be significant of the origin of this felsite, is the direction of the joint planes along the margins of several of the outcrops. In the acid and intermediate rocks of this area, in general, where they are conformable with adjacent beds, the joint planes, when present, usually show a parallelism more or less strictly in accord with the strike and dip of the adjacent beds, as well as with the direction of the flow planes. Whether these joints are in general due to contraction on cooling or to subsequent pressure or shearing, or to both, we may not be able to determine, but in the case immediately before us we see them near the margins, following the contact and turning with the latter at an angle of 90° or less. Two such occurrences can be seen, respectively at 950 paces N., 1,420 paces W., and at 810 paces N., 1,440 paces W., Sec. 26, T. 58, R. 28.

Pressure might produce joints on each side of a sharp wedge, but it would hardly make these joints unite in a curve around its edge. This phenomenon, then, of which we have already noted an example in Sec. 30, T. 58, R. 27, (p. 14), is more likely due to cooling as we sometimes see it exemplified in basic rocks, near contacts and parallel to them. It thus forms another link in the chain of evidence that points to the intrusive nature of this felsite.

On the west side of the bed **A** there are two occurrences of what might be called a conglomerate dike or vein, running northerly to northeasterly nearly at right angles to the strike of the bed. They are irregular in width, ranging from a mere seam to 4 feet, and are filled with fragments, largely of basic rock, with a few pieces of felsite among them—in a finer grained matrix. For such occurrences Wadsworth has proposed the name "clasolite."* They were probably originally fissures filled with fragments from above, like the sandstone seams mentioned on page 24. They strike in the direction of the prevailing faults in this area and like these are probably a product of the intrusion of the felsite. Other similar occurrences, or possibly apophyses from the intrusive felsite, are found at points northeast of the principal felsite outcrop, **P.**

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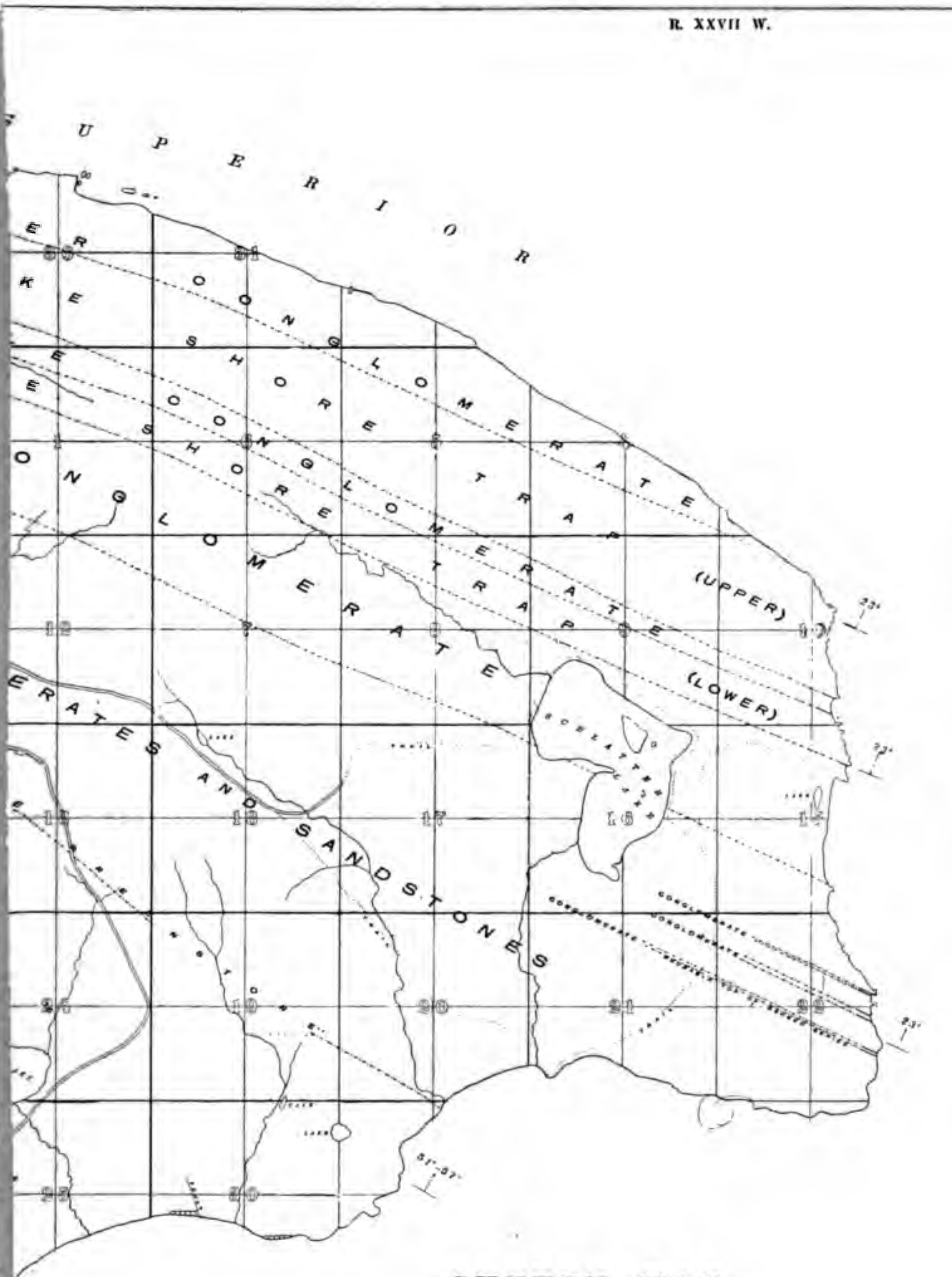
* Report of Board of Geological Survey of Mich., 1892, p. 130.



SKETCH MAP
OF THE END OF
KEWEENAW POINT
MICHIGAN

Showing the Boundaries of the Principal Geological Formations.

L. L. HUBBARD, STATE GEOLOGIST

1898

NOTE: Broken lines denote approximate locations.

above the other surface rocks, and into which their material was eventually washed.

In Sec. 21, T. 58, R. 28, about 500 paces west, the combined lower conglomerate beds appear to unite (Fig. 3) with the third or uppermost bed. From this point west to Mt. Houghton and beyond it, we find evidence of only one, rather thin bed, which from near the west line of Sec. 22 westward is underlain by a doleritic melaphyre which thereafter constitutes a persistent and characteristic bed of the series, developing further west into a typical coarse ophite.

The Bohemia conglomerate outcrops west of the center of Sec. 21 at intervals only, until it reaches Secs. 20 and 19, where it is exposed frequently for 1,300 paces, striking east and west, immediately underlain by the doleritic melaphyre above noted. On the west line of Sec. 19 it is again exposed in several broken outcrops, with the melaphyre 75 paces and the porphyrite (S. 16967) 150 paces south of it. Fifty paces south of the latter is a fine grained ophite (S. 16964). From here westward the porphyrite is well exposed for 300 paces, striking south of west. Since this same bed is in almost immediate contact with the south edge of the felsite of Mt. Houghton at the west line of Sec. 24, and the Mt. Houghton lens can be traced eastward to a point 50 paces N., and 200 paces W. of the porphyrite, it is evident that the former occupies a position between the dolerite on the north and the porphyrite on the south, equivalent to that of the felsite porphyrite and its overlying felsites further east.

We have here, then, a very interesting illustration of the progress of geological events during the early part of the Keweenawan history. The lowest of the lava sheets appear to have flowed into a trough in the Lake Superior basin, *under water*. Successive flows, after a time, increased in acidity. The accumulation of lava sheets together with the products of erosive agencies rendered the trough or basin gradually more shallow, until its upper parts were filled with acid fragmental material and a thin interbedded zone of basic lava. From this point no further accessions of very acid lavas occurred in the Keweenaw series in this area, and up to the horizon of the Greenstone there are only four known well marked conglomerate horizons, which extend with almost unbroken continuity as far southwest as Portage Lake and are essentially acid. Their material was evidently derived from the earlier acid rocks of the series or perhaps from other similar rocks south and southeast, that belonged to an earlier series.

§ 2. Mt. Houghton.

Foster and Whitney say of Mt. Houghton:

> Its summit is jasper for the distance of 150 feet, and it is difficult to trace any well-characterized lines of stratification in the mass. On the southern flank the mass apparently dips to the SSW. On the northern slope a perpendicular ledge, 20 feet in height, is observed, dipping slightly to the east; to the northeast two low ridges of jasper are seen bearing nearly east and west, and connecting with the Bare Hills by the lake shore [!] * * * In tracing it west, it gradually passes into a compact trap, with here and there an almond-shaped cavity, filled with quartz or calcspar.*

Irving describes the mountain and notes—

> abundant irregular parallel bandings in the rock of the top of the mountain. The appearance of lamination is produced by waving bands of lighter and darker shading, which are often emphasized by minute quartz seams following their direction.†

Rominger also noted the banded, laminated structure of the Mt. Houghton rock, and described it microscopically.

Mt. Houghton, 877‡ feet above Lake Superior, is a forest-covered mass of felsite of lenticular form lying east and west in Secs. 23 and 24, T. 58, R. 29, the line between which runs about 50 paces east of its summit. Along this line it is about 400 paces wide, and tapers off rapidly toward each end. (Fig. 4.) The north side, for 300 feet below the summit, has an average slope of about 30°, the south side, 200 feet below the summit, at the contact is vertical, the cliff beginning 125 paces west of the section line and extending some distance east of it. The east side of the mountain, 300 paces from the summit, is also steep, but from that point runs off in a low spur. The west side, more or less drift-covered, slopes more gradually to the middle of Sec. 23. The summit of the mountain thus forms a dome, slightly oblong, surmounting a steep east and west ridge. The immediate contact with the surrounding beds, although not often uncovered, is well enough defined to determine accurately the shape of the lens, which at 1,000 paces east of the summit appears to have narrowed from 400 paces to 50 paces or less in width. A similar decrease in width takes place towards the west, at about 200 paces west of the center line of Sec. 23, or 1,200 paces west of the summit. At 518 paces N., 768 paces W., Sec. 23, T. 58, R. 29, in the line of extension

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* F. & W., p. 65.

† Copper-Bearing Rocks of L. S., p. 181 *et seq.*

‡ Map of J. R. Mayer. See footnote, p. 44.

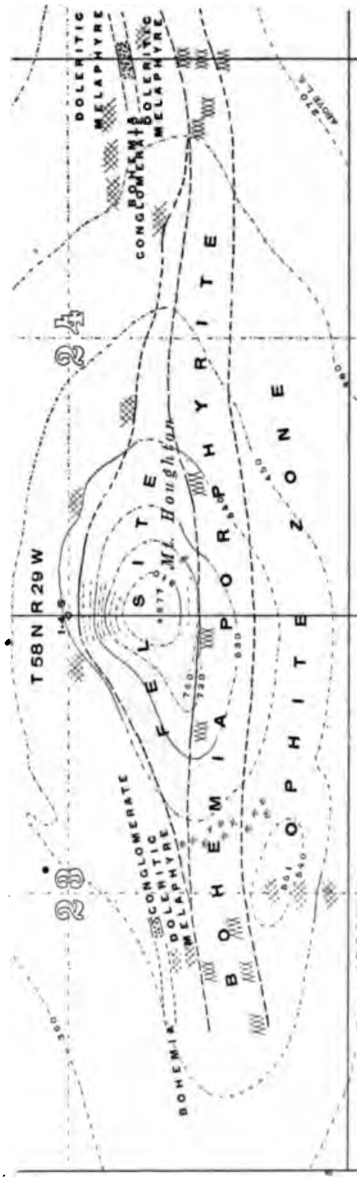

FIG. 4

Note: ▨ & ▨ *indicate outcrops.*

Sketch map of the Mt. Houghton area, Keweenaw Point.

of the mountain westwardly, occurs an outcrop of felsite that merges on the south gradually into a breccia of the same material.

From this point west for nearly 200 paces this breccia is well exposed but no more of the compact felsite. The south side of the mountain is brecciated and shattered also further east. Forty paces west of the westernmost breccia an ophitic melaphyre comes in, and fifty paces south of it is the porphyrite, so that the Mt. Houghton mass probably ends near here as above stated.

At 697 paces N., 1076 paces W., Sec. 23, the first exposure of the Bohemia conglomerate west of the east line of Sec. 24 was noted. Large blocks of conglomerate, possibly from this bed, were found at several points on the north side of Mt. Houghton, but diligent search and some digging failed to disclose the bed in place. The melaphyre immediately north of the mountain is a doleritic ophite (S. 16947, 950 paces N., 150 paces W.) like the bed that underlies the conglomerate both to the east and to the west, but since the conglomerate is also overlain by a very similar bed, indistinguishable from the former, no positive evidence could be secured to determine the relative ages of the conglomerate and felsite. All that can be said on this point with any degree of positiveness is that the Mt. Houghton felsite immediately overlies the porphyrite, **E**, and is itself probably overlain, in part at least, by the melaphyre immediately under the Bohemia conglomerate. The conglomerate, then, may have been formed above the melaphyre on the higher exposed flanks of the Mt. Houghton felsite, in like manner as the lower part of the same conglomerate was laid down against the sides of the felsite lenses at the Little Montreal River. Mt. Houghton may thus be, like these, extrusive, and may have furnished part of the material found in the Bohemia conglomerate.

A question of rather greater difficulty is the relation of the Mt. Houghton felsite to the felsite porphyrite of Secs. 26 and 27, T. 58, R. 28. Approaching the mountain from the east we last find the felsite porphyrite (Ss. 17007, 17013, 17163) in Sec. 20, T. 58, R. 28, a mile and a quarter east of the nearest known outcrop of the Mt. Houghton lens. Further west, near the east end of the lens, in Sec. 24, T. 58, R. 29, we find the porphyrite, **E**, (Ss. 16967, 17194), just below the felsite and the melaphyre just above it, so that the Mt. Houghton felsite is in the horizon occupied further east both by the felsite porphyrite and by the felsites. The felsite porphyrite, like the more acid felsite, thus appears to be of limited lateral extent.

The felsite of Mt. Houghton, in the thin section, differs in no noticeable respect from the felsites already described.

On the north side of the mountain large spherulites* were found and on this side the banded structure is plainer than on the south side. Joints, nearly vertical, were also visible at different points, striking east and west.

An analysis of the Mt. Houghton rock (S. 16951), by F. P. Burrall, M. E., gave the following results:

No. 16951. (Felsite, south side of Mt Houghton.)

SiO_2	69.76
Al_2O_3	13.14
Fe_2O_3	1.44
FeO	0.66
CaO	0.36
MgO	0.18
K_2O	11.90
Na_2O	2.52
H_2O	0.42
	100.38

The rock "at 900° C. was infusible." The specimen analyzed was homogeneous and came from 50 paces north of the south contact, or 525 paces N., 55 paces W., Sec. 23, T. 58, R. 29.

The silica present is in excess of that required for a non-quartziferous porphyry. Irving gives the silica of this rock as 76.9%† and appears to infer the presence in the latter of free quartz.

An analysis by Mr. Burrall, of a specimen from 655 paces N., 635 paces W., Sec. 24, T. 58, R. 28, near the east end of the Mt. Houghton lens, gave the following results:

No. 17193 A. (Felsite, east end of Mt. Houghton.)

SiO_2	80.05
Al_2O_3	9.73
Fe_2O_3	1.72
FeO	0.18
CaO	0.83
MnO	trace
MgO	0.00
K_2O	4.43
Na_2O	2.19
H_2O	1.03
	100.16

"At a temperature of about 900° C. this rock caked, but did not fuse."

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* Irving remarks on the apparent absence of spherulitic structure in the Lake Superior felsites. Copper-Bearing Rocks of L. S., 1883, p. 100.

† *Loc. cit.*, p. 182.

The small amount of potash, compared with that shown in the previous analysis, together with the large amount of quartz, indicates a relatively smaller amount of feldspar, and the probable presence of infiltrated quartz. The latter hypothesis is confirmed by the thin-section. If we consider 10% of the silica to be in the form of free quartz, we get the following figures:

SiO	70.00
Al_2O_3	14.59
Fe_2O_3	2.58
FeO	.27
CaO	1.24
K_2O	6.64
Na_2O	3.28
H_2O	1.54
	100.14

Except for the slight difference in soda and potash these correspond fairly well with those of the preceding analysis, but not with the composition of the felsite porphyrite. From the above analyses and those of the felsite porphyrite (p. 26) it should seem likely that the two rocks would not grade into each other, and in the absence of further evidence they may be considered as independent masses.

§ 3. The felsite of Bare Hill.

Several of the felsitic masses described in the preceding pages have been seen to be of greater lateral extent than thickness, and may properly be classed as sheets and regarded as interbedded with the more basic eruptives and their associated fragmental beds. Several other masses, however, appear, on many grounds, to be in all probability intrusive. They are not, however, very extensive, and the disturbance caused by them in the neighboring rocks, in the form of faults and shearing, does not seem to have been very violent or very far reaching.

We now come to a felsite complex, whose dimensions at the surface appear to be nearly equal in all directions. This felsite outcrops in Sec. 29, T. 58, R. 28, on and near the lake shore, and is known as Bare Hill. The first reference to it that I have been able to find in geological works is one by J. W. Foster in his report to Dr. Jackson,* in the laconic form "*Bare rock*—Jasper above, trap at the water's edge." Foster and Whitney say of this locality:

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* Ann. Mess. and Acc. Docs., 31st Congress, 1849-50, Pt. III, p. 767.

> In section 30 [29?] township 58, range 27 [28?] west of the Little Montreal River, * * * The Bare Hills here approach the coast and rise up in overhanging cliffs to the height of 80 feet, and jasper appears to be the prevailing rock. From this point it can be traced [?] inland in a westerly direction, through sections 29 and 30, in the same township and range, to the west line of section 24, township 58, range 29, expanding to a width of about half a mile.*

Irving, after having spoken of Mt. Houghton, says:

> The same felsite shows in the Bare Hills, in Sec. 29, T. 58, R. 28 W., and beyond on the lake shore in section 28. Similar rocks appear on the east point of the bay† into which the Little Montreal River empties [!], * * * and it would appear probable that the Mount Houghton rock, along with some smaller elevations leading off from it in an easterly direction, belong with the more easterly of the exposures on the coast, while the Bare Hills belong to another belt.

Irving maps the Mt. Houghton belt as extending some distance east and west from Mt. Houghton, and a second belt of quartz-porphyry and felsite as running through the southern part of Bare Hill eastwardly in such a direction as probably to include the Fish Cove felsite in Sec. 35, T. 58, R. 28. Rominger does not appear to have examined Bare Hill except from the shore.‡

The rounded mass of this mountain rises rather rapidly from the shore of Bête Grise Bay to a height of 584 feet.§ It is flanked on the south by a shore cliff about 180 feet in height, which extends, probably with a varying altitude, more or less regularly along the south face of the Bohemian Range, within a hundred paces of the water's edge, from the middle of Sec. 26, T. 58, R. 29, to Sec. 26 of the range next east. This shore cliff, vertical in Sec. 29, here marks the edge of a fairly well defined terrace which runs back until it meets the main cliff which on the southeast side rises thence vertically almost to the summit of the mountain. The rounded mass of the latter at this point is less covered with vegetation than further north, and stands out as one of the prominent landmarks on this part of the coast. The annexed illustration (Fig. 5), from a photograph taken from the shore just east of the mouth of Little Montreal River, brings out the relation between the shore cliff and the main mass, and the relation of the latter to other parts of the range. In the background, down the range, Mt. Bohemia also rises into prominence.

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* F. & W., p. 65.

† Copper-Bearing Rocks of L. S., p. 182. Irving evidently refers to the felsites of Fish Cove which is half a mile east of the river.

‡ Geol. Sur. Mich., V. Pt. I, p. 136.

§ According to map of J. R. Mayer, 1865. "Survey of the North and Northwestern Lakes." This map is on file in the War Department, Washington.

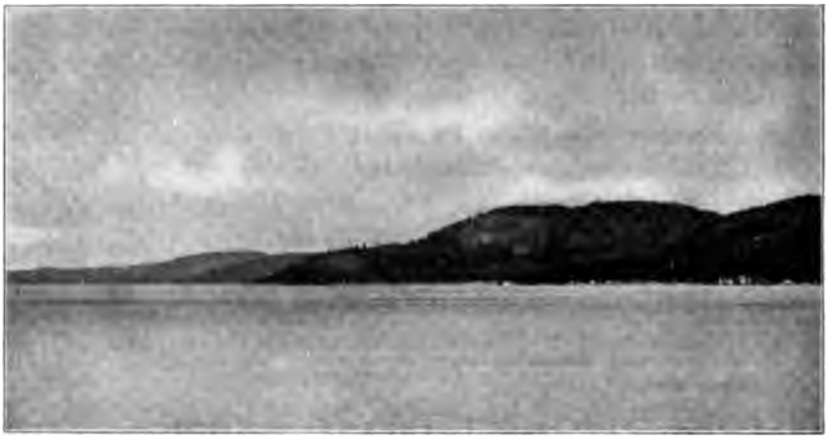

FIG. 5. Bare Hill, from mouth of Little Montreal River.

Under the microscope this rock (S. 17017) shows a mosaic of closely interlocking quartz and feldspar, stained red and dotted with iron oxide. Interspersed in the groundmass are roughly shaped feldspar laths with small extinction angles. Grains of fresh quartz, in part if not wholly secondary, are scattered over the section.

The steep sides and much of the eastern summit of Bare Hill are well exposed, and the frequency of outcrops fortunately makes the geology of this hitherto neglected and interesting mass quite plain. The felsite prominent in the principal cliff appears in a belt 275 paces wide, forming the western summit of the mountain along the west line of Sec. 29. It is bordered by melaphyre both north and south. Cross-section, Figure 6, adapted from the contour sheets of the U. S. Lake Survey, is drawn through the mountain north and south about 500 paces east of the west line of Sec. 29. An inspection of this cross-section might seem to confirm the conclusions drawn by Irving from a similar phenomenon on the Minnesota coast,* where a band of quartz porphyry was found between two beds of diabase, as if interbedded, i. e., extrusive. If we imagine the rocks in the above section dipping at a small angle instead of a large one, we have a

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* *Loc. cit.*, p. 314 *et seq.*

east side of the mountain, the melaphyre in contact with the felsite is much shattered. The felsite thus for 2000 feet is flanked by the melaphyres and conglomerates, and has cut across them at right angles to their strike and lifted the beds on the east side. These melaphyres, as far as observed, are mostly of the ophitic variety, and in places are very coarse grained. They evidently belong to the broad belt of this rock heretofore noted, which is prominent at many points along the south side of the Bohemian Range.

No connection was seen between the lake shore felsite and that of the higher parts of the mountain. The former is seldom exposed except on the south edge of the cliff, and elsewhere in huge blocks near the water, under which, for some 200 feet from shore, its eastern end extends. Here it shows a good contact under water, with basic rocks on the east, nearly at right angles with the shore line. At this point, in a small cove, we find the felsite on one side brecciated, and between it and the felsite on the other side there is a small outcrop of melaphyre, which appears to extend northeast through a small cleft to the melaphyre on the other (northeast) side. These large blocks of felsite were thought by Rominger* to be "loosened masses, slid down," which is possibly true also of the principal shore cliff.

The contour lines in the above plat (Pl. V) are adapted from the Lake Survey map,† with some modifications sketched from memory, to indicate a few minor details not shown on that map.

§ 4. Evidences of disturbance along the shore.

The main masses of the Bare Hill felsite being thus evidently intrusive, a few observations made along the adjacent shore and elsewhere may be not without interest.

The north shore of Bête Grise Bay as far east as Fish Cove is in general difficult of access—from the land side on account of thick underbrush and lack of trails, and from the water side on account of scarcity of landing places and because of the heavy surf that dashes against the rock-bound margin in any but the calmest of weather. It is evidently for these reasons that this part of the Keweenaw series has perforce received so little attention, the observations there having been in most cases made from row boats skirting the shore at a safe distance from the breakers. This is particularly true of that part of the shore immediately south of Bare Hill.

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* Geol. Sur. Mich., V, Pt. I, p. 136.

† J. R. Mayer. Survey of the North and Northwestern Lakes. War Department, Washington.

In general the basic rocks that line the bay show signs of disturbance and of weathering. They are much broken and fissured, carrying veins of laumonite and calcite, and sometimes of prehnite and copper. No regularity is apparent in these fissures. They strike in many different directions. The trap rocks exhibit no uniform bedding, sometimes none at all. Sometimes one can easily make out such a bedding as one's theories may require. There are, however, frequent and positive signs of slipping of the rocks lakeward at angles of 45° or steeper. One such occurrence is especially noticeable, west of the sandstone and east of the felsite, near the center line of Sec. 29, T. 58, R. 28, along a melaphyre conglomerate, which shows a lakeward slipping of both foot and hanging walls, there being several inches of fluccan on the foot. Near the same locality a block of trap apparently in place projects into the water. On its west side is seen a band of amygdaloid between two bands of more compact trap, all striking about N. 20° E. and dipping 45° S. E.

On the west side of Bare Hill no evidences of unusual disturbance were noted along the contact with the felsite. On the east side evidence already noted indicates that the beds there have a northwesterly-southeasterly strike. This and the cases just noted along the shore, together with the fallen masses of felsite near by, should seem to indicate that these phenomena, otherwise rare in the Keweenaw series, are due, in part, to the protrusion of the felsite, and in part to undercutting by wave action, and subsequent sliding into the lake of immense rock masses. At a center of disturbance like Bare Hill, the adjacent rocks would be particularly susceptible to movements of this nature. To such movements also is attributed the presence of the conglomerate outcrops on the shore west of the above point, or about 150 paces east of the west line of Sec. 29. Further reference will be made to them on a subsequent page.

§ 5. Flexure of beds north of Bare Hill.

We have already seen (Pl. IV) that the Bohemia conglomerate in its westward course from the Little Montreal River, in Sec. 27, T. 58, R. 28, begins to swing more to the north, and when within a mile of Bare Hill it and its immediately underlying beds—the acid zone—curve around the mountain in a direction parallel with the north and east faces of the latter, as outlined along the felsite outcrops. So far as the observations of the Survey go, there is no reason to doubt that, excepting the conglomerate above noted, the melaphyres and fragmental rocks beneath this acid zone practically are conformable with the latter, except that the dip increases as we approach the older beds of the formation on the south. Dips of 72° were noted in the melaphyre on the east side of Bare Hill, and of about 80°, in the conglomerate on the west side, as already stated. The northern side of the Bohemian Range is rather more drift-covered than the southern, and falls away gradually into the Little Montreal River valley, the opposite or northern side of which is shut in by the Greenstone Range. It was along the southern face of the latter that exploration was dominant in the early days of mining on Keweenaw Point. From Mosquito Lake eastward, the Wyoming, Empire, Bluff, Iron City, Etna, Hanover, Montreal, Star, Copper Harbor, Philadelphia and Boston, and Keweenaw Companies worked upon or explored for fissure veins that in general crossed the formation in a direction slightly west of north, frequently if not always disclosing their whereabouts by topographical breaks in the range. The Allouez conglomerate lies immediately under the Greenstone, and its exposures on the surface and in the works of the mines serve to mark the south boundary of the lustre mottled "greenstone" or ophite, whose coarsely warty weathered surface is well seen in ledges, and in detached blocks that are strewn along the sides of the ridge. (See Part I, Pl. VII).

§ 6. Strike and dip of beds above the Bohemia conglomerate.

A. Strikes.

For some miles west of Mosquito Lake the Greenstone Range runs east and west. At the east end of the lake, however, in the northwest corner of Sec. 14, T. 58, R. 29, a mile and a half north and a little west of Mt. Houghton, it trends more northerly, then swings east again, and then more southerly (Pl. IV). In Sec. 13, T. 58, R. 28, on the property of the Keweenaw Mining Company, the course of the Allouez conglomerate as taken from an old map of the location by H. F. Quarré d'Aligny, and by Wm. H. Stevens, one of the

Keweenaw pioneers, is from about 1650 paces north, on the west line of the section, to 120 paces west of the southeast corner on the south line of the section—an apparent strike of about S. 49° E. From below the latter point in the north part of Sec. 24, immediately south, the above map shows the conglomerate swinging more to the east around the east flank of the range and falling rapidly away with the latter.[*]

The range sinks to the general level of the country, which is comparatively low from here to the end of Keweenaw Point. Former geologists[†] and old geological maps,[‡] because of this decided eastward curve in the course of the conglomerate outcrop or for other reasons, mark the Greenstone bed as running to the east part of Sec. 21, T. 58, R. 27, but the flat northeast dip of the conglomerate (35° according to the above map of the Keweenaw location[§]) and the rapid decrease in altitude of its outcrop, and possibly some faulting,[¶] have a good deal to do with its apparent eastward trend at the point indicated. A careful examination of the shore in Sec. 21, where the old maps indicate the emergence of the Greenstone, failed to show any rock that corresponds in character with it. Furthermore, the only rock on the beach there that might be taken for a conglomerate is an amygdaloid more or less scoriaceous, whose top in places appears to be slightly conglomeratic, but without evidence of sandy matrix, such as is common in melaphyre conglomerates in this district. This bed strikes N. 65° to 67° W. Noteworthy is the fact that very few fragments of lustre mottled melaphyre are to be seen along this shore east to the end of the Point and no beds of that rock until we reach a spot 600 or 700 paces north of the extreme southeast point. If the Greenstone does take the course laid down on the old maps, it must have wedged out and disappeared west of here.

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[*] Cf. contour map of J. R. Mayer, 1865. Survey of the North and Northwestern Lakes, War Department, Washington.

[†] F. & W., *loc. cit.*, p. 62, say: "A few yards south of the extremity of the point, and near the north line of Sec. 27, a band of conglomerate is observed, attaining a thickness of sixty feet, bearing N. 70° W. and dipping NE. 16°. The underlying trap differs from that which overlies the detrital rocks, being more amygdaloidal, and offering less adhesion between the particles. This is supposed to be a continuation of the great metalliferous belt, as developed at the Cliff, North American, and Northwest mines," i. e. the belt next below the Allouez conglomerate.

[‡] Map of Stevens, Hill and Williams, also Pl. XVII, Copper-Bearing Rocks of L. S.

[§] F. & W. give the dip of the conglomerate in range 28 as 40°. *Loc. cit.*, p. 62.

[¶] See p. 17.

On the other hand, an examination of the shore immediately south of the north line of Sec. 29, T. 58, R. 27, showed a bed of coarsely lustre mottled melaphyre or ophite, 150 paces wide, capped by an amygdaloid with another ophite and amygdaloid over it, the whole being 225 paces wide. This may not be the full measure of the ophite belt, which may have suffered from erosion on the north. Under the lower of these two ophites is a well characterized amygdaloidal conglomerate, which, it is true, does not resemble the Allouez conglomerate as we usually find it elsewhere, but conglomerate beds change from point to point. This ophite complex runs back from the shore in a well marked ridge crossing the north line of Sec. 29, about 300 paces west of the center, and disappears in low ground southeast of a grassy meadow in the S. E. ¼ of the northwest adjoining Sec. 19, thus leaving a gap of less than a mile to the end of the Greenstone ridge in Sec. 24. What is very significant, however, is the occurrence along the southwest side of this ophite ridge of large, smoothly waterworn boulders of ophite, very coarse grained, and in all respects like the blocks that line the south face of the Greenstone further west. No such coarse grained ophite beds are known at greater distances than two hundred or three hundred feet south of the Greenstone, until we reach the Bohemian Range, and even here they are hardly as coarse grained. These circumstances might not be conclusive evidence of the identity of the shore outcrops with the Greenstone, but the trend of both ridges and the short gap between them are circumstances that cannot be overlooked. They should seem to outweigh former inferences grounded not even on lithological resemblances, and I have no hesitation in marking the course of the Greenstone in accordance therewith.

The curves of the Bohemia conglomerate and of the Greenstone, east of Mt. Houghton and Mosquito Lake respectively, are thus seen to be in close correspondence. These curves will be slightly more accentuated if projected to lake level. That the general symmetry of these curves has not been disturbed to any great extent is positively known of the Bohemia conglomerate and is made probable of the Greenstone by the best attainable evidence on record. Old mine location and other maps indicate faults in the Greenstone, generally striking west of north, but they also indicate only slight disturbances. If we select as a center of disturbance a point at Bare

Hill or further south, the curves above noted would be the natural result of an uplifting force acting at that point, or of an obstruction around which the overlying strata were bowed. The lines of fracture caused by such flexing, not as radii from the center of upheaval but more or less inclined to these radii, are also in accord with similar phenomena observed elsewhere.*

The Bare Hill massif may be only a part of a greater mass not now exposed to view. We find west of it in Sec. 30 at the foot of the shore cliff, about 100 paces back from the lake, another smaller outcrop of acid rock just under a pebble conglomerate that is undoubtedly the same bed as the cut-off conglomerate at Bare Hill. This rock contains some phenocrysts of feldspar and corroded quartz, in a groundmass in which the feldspar does not interlock with the quartz as intimately as in the Bare Hill felsite, and the feldspar laths here are rather more abundant and better defined. It is a quartz porphyry.

The relations of the rocks here are confused, but an acid porphyrite also occurs above the conglomerates. Whether the porphyry (compare page 45) is intrusive or not could not be determined. It is, at all events, another indication that we are here in a zone of acid rocks that may be laccolitic sheets, offshoots from a parent mass that once may have existed further south.

B. Dips.

As already noted, the prevailing dip of the Bohemia conglomerate is 54°. North of that horizon we have no records of the dip of overlying beds until we reach the Allouez conglomerate immediately under the Greenstone. Foster and Whitney, as previously stated, give the dip of the Allouez conglomerate as 40°.† This evidently refers to the area here under consideration, but is greater by about 9° than the dip measured by the writer on the Allouez conglomerate and on the foot wall of the Greenstone in an adit on the Star location in Sec. 9, T. 58, R. 28. Further west, at the old Pennsylvania location‡ (Sec. 15, T. 58, R. 30), and possibly at Mosquito Lake also, the dip is 23°.

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* See Woodworth, On the Fracture System of Joints, B. S. Nat. His., 1897, pp. 163-184, and authorities cited.

† *Loc. cit.*, p. 62.

‡ Geol. Sur. Mich., V, Pt. I, p. 130.

The dip of the Great conglomerate opposite the last two points accords nearly with that of the Allouez. At Manganese Lake, however, according to Foster and Whitney* it is 25°, which may be a misprint for 35°, for on the old road that runs from there east to the manganese deposit in the northeast quarter of Sec. 4, next adjoining, it is 35°-36° in the same horizon as at Manganese Lake, and at several points west of the latter dips of 27°-30° were noted. Dips of 34°-36° were also measured on a sandstone of the group above the Greenstone, west of the Clarke location, near the south line of Sec. 4, and almost equally steep dips in the Outer conglomerate on the lake shore west of Copper Harbor.

There appears, therefore, to be a belt of which the Greenstone forms a part, in which the dips are flatter than those of the overlying beds. Similar relations appear to hold good in the same zone opposite the Central mine,† and at Eagle River gap where the increased dip, going northwest from the Greenstone, amounts to at least 6°.‡ (See Chap. IV.)

At the extreme end of the Point, beginning on the lake shore in Sec. 10, T. 58, R. 27 at the hanging of the Lake Shore trap group of Irving, which is exposed for one mile north and south, we find the strike about N. 60° W., and the dip 23° N. E. Near the hanging of the conglomerate ledge that forms the north side of High Rock Bay, the dip is 22°-23°. A conglomerate 60 paces wide, south of the center line of Sec. 22, gave dips of 23° and 24°, and another conglomerate 13 paces wide, about 250 paces north of the south line of Sec. 22, gave a dip of 23°. This is the lowest pebble conglomerate observed by the Survey in this section and appears to be the one of which Foster and Whitney record an observed dip of only 16°, and a strike N. 70° W. Foster and Whitney evidently considered this the Allouez conglomerate.§ The hanging is a chloritic melaphyre (Sp. 17619), in no wise like the Greenstone.

It thus appears that the average dip across the extreme end of the Point is not greater than about 23°.

On the lake shore in Sec. 29 of the same township, between the most easterly felsite and the conglomerate immediately under the ophite that we have assumed as the east end of the Greenstone, no conglomerates were seen. The joint planes in the melaphyres and the contacts between melaphyre and conglomerate gave no very satisfactory dips, but approximate dips of 51° to 57° were noted, the steeper dips being the further south, i. e. nearer the felsite horizon. The average strike of the beds was N. 65° to 70° W.

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* *Loc. cit.*, p. 103.

† Copper-Bearing Rocks of L. S., Pl. XVII.

‡ Cf. Marvine, Geol. Sur. Mich., I. Pt. II, p. 96.

§ See foot note, page 50.

§ 7. Significance of strike and dip.

It may be remembered that the dip of the contact at the hanging of the felsite in Sec. 30, T. 58, R. 27, first described, was 80° N. The overlying beds along the lake shore appear, then, to decrease in dip, in a distance equivalent to one mile at right angles to the strike of the formation, i. e., as far as the Greenstone, from some indeterminable figure (80° or less) to something like 31°. From the Greenstone east for another mile no outcrops appear, but at a mile and a quarter above the Greenstone, still at right angles to the strike, we reach a horizon in which further east on the lake shore the dips have decreased to 23°, an inclination they steadily maintain for an additional two miles, up to the Outer conglomerate. Whether the change of dip from the Greenstone north (from 31° or more to 23°) is gradual, as at other points further west, or whether it takes place immediately above that bed, in the nature of an unconformity, may never be known, for the area in question is flat with few or no outcrops. If it does, however, the unconformity is purely local and may be due to the intrusion of a small mass like that in Sec. 30, T. 58, R. 27, whose age would thus be marked as just subsequent to that of the Greenstone.

It is evident, however, that whatever may have been the force that tilted the beds in this immediate area (Secs. 19, 20, 29 and 30, T. 58, R. 27), the visible effect of that force—excepting the steeper zone above the Greenstone—decreases in intensity from south to north. The uncertainty of the exact nature of the felsite in Sec. 30, whether intrusive or extrusive, the absence of other positive data, and the probability that, owing to topographical conditions, no more positive and convincing evidence can be gathered here, render unsatisfactory any inferences we might draw as to what the tilting force at this point may have been.

From the Bare Hill massif, however, dips decreasing towards the northwest, north and northeast, and, so far as known, steeper towards the north than in corresponding horizons further west and further east; beds swinging out of their previously regular course to curve symmetrically and in approximate conformity around the northern flank of a mass of felsite known to be intrusive—these are phenomena that may be readily and naturally explained, in great part, at least, as those of effect and cause—the flexure of beds above and around an intruding mass.

That all of the known beds of the copper-bearing series on Keweenaw Point above the Bare Hill horizon were affected by this agency, if any of them were, also seems probable from their apparent close conformity. This is well shown immediately east of Mosquito Lake (Pl. IV) where the courses of the beds are easily followed. The age of the Bare Hill intrusives, if these be connected with the above phenomena, may then be later than that of all the rocks that overlie them in the series on Keweenaw Point. But this conclusion may not be accepted as final until we know that the later, flatter-dipping part of the series, does not now occupy a position approximately the same as that in which it was laid down.

§ 8. Relation of lava flows to contemporaneous conglomerates. In order better to understand the chain of events that may have led to the establishment of the beds of the Keweenaw series in the positions in which we now find them, and to explain, if possible, some apparent anomalies that we shall meet on subsequent pages, a few considerations of a general nature may properly here claim our attention. The components of that series are, (1) lava sheets, which are the so called original product of volcanic action and were extravasated from the interior of the earth, either with or without violence, from craters or more probably from fissures, and spread over parts of its surface as flows (we are not here considering dikes), and—(2) conglomerates or sandstones, secondary products, which are made up of the more or less rounded débris of the volcanic, and to a less extent of the other, rocks. These two classes of rocks, the eruptives and the fragmentals, while in some respects they both belong in the domain of fluvial and of sedimentary geology, such, for example, as in their attainment of, and distribution over, the lower parts of a basin, and in the tendency of their upper surfaces, under favorable conditions to preserve or to assume a position approaching horizontality, appear to have some divergent tendencies that can not be overlooked. An overflow of lava, if sufficiently liquid, will, like an overflow of water, seek the nearest depression or channel and will discharge itself through this if the latter be of sufficient width and depth, without rising over its sides. Such a lava stream is called a *coulée*. Lava issuing simultaneously from different parts of a fissure on a mountain side might find several such channels and build several distinct coulées, or, if the discharge were sufficiently copious the result might be one broad sheet, of varying thickness according to the furrows in the slope over which it flowed.

A lava flow, however, unlike a flow of water, may find its fluidity impeded if not altogether checked by its rapid loss of heat and consequent increasing viscidity and may finally come to rest on a downward slope without having reached the lowest level. If such a lava stream were quite acid, its lateral flow like its downward flow might proceed but a short distance and it might solidify in a mass thick at the center and tapering out at the sides—lens-shaped. Such seem to have been the forms of some of the felsite extrusions. The slope of a consolidated lava stream may be of almost any angle up to 40° and even 45°, and Geikie says that, "Even when it consolidates on a steep slope, a stream of lava forms a sheet with parallel upper and under surfaces, a general uniformity of thickness, and often greater evenness of surface than where the angle of descent is low."* In trying to account for the structure of the Keweenaw series we can therefore agree with Irving that the lava beds may have had their source in the rim of the Lake Superior basin—a trough of pre-Keweenawan origin†—and aside from the probability that the less basic flows, by more rapid cooling, contributed to raise the rim of the basin relatively to its center, and thus gave a steeper gradient to some of the subsequent flows, there must even in earlier Keweenawan times have been a difference of altitude between the basin rim and its center, and we cannot therefore follow Irving and Chamberlin in their conclusion that the Keweenawan beds were originally laid down in a position of almost absolute horizontality,‡ if these writers mean this to apply equally to all parts of the beds, or, especially, to those beds that may not have reached the lowest part of the basin. The "rim of the basin" is a somewhat indefinite term, but we know that many dikes of similar character to the melaphyres of the Keweenaw series cut the Archean in the high land of the Gogebic Range and northeasterly as far as the vicinity of Marquette. The presence of dikes in those areas is as marked as is their absence on Keweenaw Point, and while the sources of some of the earlier Keweenawan flows may possibly now be buried under Keweenaw Point, the assumption that the Gogebic and other known dikes are the sources of at least a part of the flows, can certainly not be regarded as improbable.

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* Geikie's Geology, 1885, p. 211; 1893, p. 226. This is evidently not meant to apply to the most acid extrusions. See also Dana, Characteristics of Volcanoes, 1890, pp. 13, 148.

† Copper-Bearing Rocks of L. S., p. 418.

‡ Bull. 23, U. S. G. S., p. 101.

It is admitted by more than one writer that the basin now occupied by the Keweenaw series was formed in pre-Keweenawan time, but in order to account for the dips of the Keweenaw series from all parts of the basin rim towards its center, a further gradual subsidence of the basin center is assumed to have gone hand in hand with the upbuilding of the series, and this, too, in face of the fact that the basin lies in what is characterized as the "stable Azoic."* If such a subsidence has taken place, we have no satisfactory measure for it, because we do not know how deep the basin was in pre-Keweenawan time, and, moreover, the admitted previous existence of such a basin weakens, *ipso facto*, the argument that a great subsidence must have taken place in its central parts during the accumulation of the Keweenaw series—in consequence of that accumulation. If the extravasation of the lavas was from the rim, there should seem to be no conclusive reason for placing the source of the extravasated material immediately under the middle parts of the present hydrographic basin rather than without the area of extravasation and immediately contiguous to it, and if the greatest accumulations of volcanic material were in the rim of the basin on the underlying Archean, there should seem to be more reason to suppose a regional subsidence involving the rim of the basin and known areas of the Archean, than a local subsidence of the center of the basin where these accumulations should seem to have been of less magnitude.† The differential subsidence, therefore, can at most be regarded as a relative change of level of different portions of the beds, due to plication or folding of the beds in the general process of mountain building, a process that had already begun in pre-Keweenawan time.

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* Dana's Manual of Geol., 1869, p. 199. Irving supposes the granite-gneiss complex of the Huron mountains to run across Lake Superior to the Canadian shore. Geol. Sur. Wis., II, p. 458.

† Compare the difference of thickness of the series on opposite sides of Lake Superior (this volume, Part I, p. 101). See also *infra*, Chapter IV.

Whether we believe in a subsidence of the middle parts of the basin, due to the accumulation of Keweenawan material in them, or to the emergence of the Archean on either side of them, due to folding or otherwise, we must consider the Keweenawan lavas in great part as issuing from sources situated at some distance above their ultimate level, for the degradation of the original vents of the lava flows in post-Keweenawan times, which amounts to several thousand feet, must also be taken into account. The lavas, then, in order to reach the bottom of the basin must have had a very appreciable gradient and could therefore not show throughout every part of their course even a close approximation to horizontality. The higher the elevation of their source, *ceteris paribus*, the steeper their gradient was likely to be. In studying the lower beds of the Keweenaw series near Portage Lake we shall find many irregularities that point to this area as being a part of the basin rim over whose slopes the early lavas poured with different degrees of steepness, rather than as belonging to that part of the basin over which the earliest lavas and conglomerates were spread in a nearly horizontal position. If this conclusion be well founded, its importance is great, for if the edges of the Keweenawan beds now exposed along the contact with the Eastern sandstone are but the eroded margins of these beds where they rested on the slopes of the basin rim, we are here near the eastern limits of the lower levels of the pre-Keweenawan basin, and whatever parts of the Keweenaw series lay still to the eastward must have been at higher levels and therefore were involved in the post-Keweenawan erosion that cut out Keweenaw Bay. In short, by accepting some such theory we shall not have to expand the thickness of the series indefinitely to the east beyond its visible limits, or to suppose the presence of a great reverse fault that caused the depression—not of the basin center, but of its margin.

That the surface of the earth in the Lake Superior region showed in pre-Keweenawan times the usual diversities of an eroded landscape may well be assumed when we reflect that some 14,000 feet of Huronian rocks had been carried away and that some folding of the strata had taken place, before the lava flows began.* Whether the area now covered by the waters of Lake Superior was then one great trough, or formed two distinct basins, into each of which flowed lava streams from their several sources, north, south, east and west, is a matter that can never perhaps be determined. With the exception of a few marginal remains on the eastern shore and on Michipicoten Island, we now find the Keweenawan lavas of Lake Superior confined to the western part of the basin whose axis lies nearly northeast and southwest, in general terms parallel with the axes of Isle Royale and Keweenaw Point, and also with a series of troughs† northwest of the lake in Canada, in which appear remnants of folded Huronian rocks. That Keweenaw Point formed the southeast margin of the western basin at an early period of Keweenawan time, is made probable by the irregularities and apparent unconformities observed between strata in the lower part of the series, and by the character of some of the older conglomerates, whose angular fragments indicate proximity to the shore line on which they were laid down.‡ This inference should also seem to be strengthened by the immense thickness of the Great conglomerate on Keweenaw Point and its marked and rapid decrease in thickness§ where it diverges from the Greenstone Range at the end of the Point, and the indication that this bed is therefore following a course that would make its section at lake-level parallel with the outline of the Archean terrane of the Huron Mts. on the south.

Lava streams issuing from fissures in the margin of the basin flowed down the valleys toward the bottom of the basin, consolidating in their channels or finally spreading over the bottom in wider sheets, until having filled the valleys with beds of varying thickness and finally covered the highest projections of the older formations they built up a series of strata that show an almost ever decreasing divergence of dip and strike, that is, a more widespread uniformity towards the end of the period, when the latest beds were practically conformable over wide areas. Some such hypothesis should seem to be in accord with facts observed in other volcanic regions and seems to offer an explanation of phenomena that in the light of these facts presents no inherent difficulties.

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* Irving and Van Hise, The Penokee Iron-Bearing Series of Michigan and Wisconsin. Mon. XIX, U. S. G. S., 1890, p. 460.

† See 5th Annual Report, U. S. G. S., Pl. XXII.

‡ See Chapter V.

§ See *infra.*, § 9.

It thus appears that there is no reason to believe, from the present position of the Keweenaw lava beds, that they must originally have been everywhere horizontal, and that the dips now observed in the later beds are due wholly to a subsequent tilting. Let us see if the testimony of the conglomerates militates against the above conclusions. The lavas and interbedded conglomerates of the Keweenaw series are closely parallel, if we except some cases of discordance, already alluded to, that will be taken up later. Therefore the original positions of these two classes of strata must have been similarly parallel. If the lavas were horizontal, the conglomerates must have been almost equally horizontal, or both may have been originally laid down at an angle to horizontality. It is well known that conglomerates, made up of rocks that occur along a shore line, are built up, within the limits of wave and current action, on the shelving sea bottom sometimes at an angle receding from the shore, an angle that may be as high as 24°* if not higher, and it should not seem to need proof that as distance from the shore—the source of the pebbles—increases, these beds (as contradistinguished from sandstones) must grow thinner,† and probably do then become more nearly horizontal, conforming to some extent, perhaps, to the irregularities of the bottom. The possible angle of deposition of the conglomerates near their margins thus falls within the gradient limit of the lava flows and there is therefore no reason why a lava stream flowing into a sea and spreading over its bottom may not be approximately conformable with a conglomerate formed either below or above it, and yet neither of them at the shore may originally have been horizontal.

From the above it follows that a conglomerate may be laid down on the margin of a sea bottom whose shore line may describe a curve with a short radius, the dip of the conglomerate remaining the same at all parts of the curve, its strike, however, changing constantly, so that from being north and south at one point, it may be east and west at another. A lava sheet flowing over this bed might spread laterally over a considerable segment of it, but might not and probably would not be co-extensive with it, especially if the

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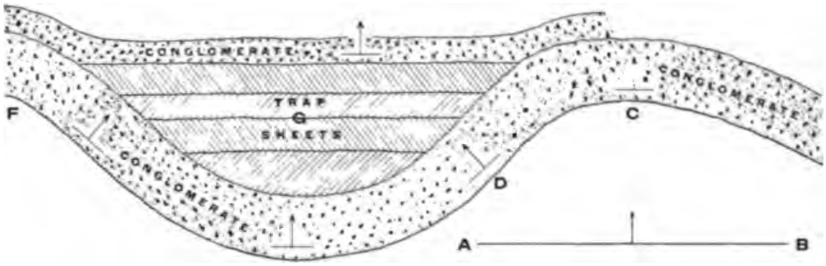
* Gilbert, Geol. of the Henry Mountains, p. 52.

† Cf. Russell, Bull. U. S. G. S., No. 108, p. 33.

convexity of the shore line were great. Several flows of lava of similar character might, however, overlap and together cover adjacent segments of the conglomerate for a great distance laterally, and if these several sheets could not be differentiated, we might be left in doubt whether to ascribe the tilted position of the several beds to an origin similar to that just described, or to a subsequent earth movement. This is perhaps the greatest difficulty against which we have to contend on Keweenaw Point, and we cannot hope in every case to reach a conclusion that will be free from uncertainty. We may also note here the effect that a subsequent tilting of the formation would have on the dip at different points. In Fig. 7, suppose the dips in the conglomerate at C and D and at all points between them were originally equal, and that the strikes at those two points differ by 90°. If the beds are tilted towards C around the axis A B, they must turn at least 90° before the dip plane at D becomes vertical, but less than 90° to make the dip plane at C vertical. In other words a certain amount of tilting has its maximum effect at C and on all planes parallel to C, the effect being less for every point of the curve from C to D.

FIG. 7



Ideal sketch, to show difference of strike in beds of the same series.

Again, a shore line might consist of two adjacent convex portions, C and F, and a lava sheet or sheets might be deposited in the trough formed by these curves, G, and covered by a later conglomerate. These beds would then be apparently unconformable, laterally, with an underlying conglomerate, although belonging in the same series.

There seems to be nothing in the foregoing discussion that would militate against the conclusion reached on a former page, that the Bare Hill intrusion may be connected with intrusive phenomena later than the Outer conglomerate of Keweenaw Point. If, however, this and the Great conglomerate were laid down against the sides of the older formations after the flexure of the latter, we might, perhaps, in the absence of marked disturbances, expect a greater uniformity of dip in these conglomerates between Eagle River and the end of Keweenaw Point than we now find there. But if this difference in dip be due to irregularities in the surfaces of underlying beds, or if another phenomenon, slide-faulting,* should be found to have prevailed to a great extent in the area west of Copper Harbor, by which the dips of the beds there have been reduced subsequently, the questions of the relative ages of the Bare Hill felsite and the Great conglomerate, and of the conformity of the Great conglomerate with lower members of the series, must still be left open. This phenomenon will be taken up in the next chapter.

§ 9. Thickness of the Great conglomerate and underlying formations.

In order to compare the higher beds of the series in the Schlatter Lake area at the extremity of Keweenaw Point with corresponding beds at Eagle River, as measured and described by Marvine, some figures may be of service. They are based on the following facts and assumptions. The strata between the Outer conglomerate (Pl. IV) and the lowest observed conglomerate in Sec. 22, T. 58, R. 27, as already stated, have a very uniform dip, averaging not over 23°. The strike observed uniformly throughout the Lake Shore trap here was N. 60° W. Lower in the formation the strike, based on less satisfactory observations, was thought to be nearly the same, although Foster and Whitney give it as N. 70° W. We have seen that the probable strike of the beds under the Greenstone in Sec. 29, T. 58, R. 27, is about N. 65°-67° W. We may therefore safely assume for the Greenstone itself a strike of N. 67° W. What dips prevail in the beds between the lowest conglomerate in Sec. 22 and the Greenstone, is not known, but if we take the average (27°) between the extreme observations (23° and 31°; see preceding pages) and multiply the horizontal distance, 7200 feet (including that across the Greenstone), by the sine of the dip (0.454), we find the hypothetical thickness for the beds next above the Greenstone to be 3270 feet. The thickness of the beds between these and the Great conglomerate can be measured with a near approach to accuracy. Scaled from the map (Pl. IV) they are 3353 feet wide or (x sin 23° = 0.39) 1308 feet thick. The thickness of the Great conglomerate (Pl. IV; Great and Middle conglomerates and Lower Lake Shore trap), computed in like manner, is (4594 x sin 23° = 0.39) 1792 feet; that of the (Upper) Lake Shore trap, (2724 x sin 23° = 0.39) 1062 feet.

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* See Chap. IV.

In the preceding paragraph I have included within the Great conglomerate formation a number of melaphyre beds grouped by Irving with the Lake Shore trap, together with a thick bed of conglomerate that overlies them and separates them from the higher beds of the same group.* This was temporarily necessary for comparison's sake, for between the end of Keweenaw Point and Eagle River no distinction has ever been made between the Great conglomerate and the bed just mentioned, which I take to be the same bed that lies between Copper Harbor and Lake Fanny Hooe. Both have been regarded and mapped by previous geologists as the Great conglomerate, and Marvine's measurements at Eagle River, were made on this assumption. This higher conglomerate bed I have called the Middle conglomerate, as will be explained later.

At Copper Harbor the Lake Shore trap, within the limits and with the dip (35°) usually ascribed to it, is about 1100 feet thick, and the Great conglomerate (embracing the limits heretofore assigned to it at that point), with the same dip, must be upwards of 2500 feet thick—not far from its calculated thickness at Eagle River and other intervening points.

Tabulating the above figures on the basis of the foregoing correlation, we have the following:

	End of Keweenaw Point.		Copper Harbor.		Eagle River.
	Dip.	Thickness.	Dip.	Thickness.	Thickness.
Lake Shore trap. (Upper)	23°	1062	35°	±1100	Not exposed.
Great congl. (including Middle congl. and L. S. trap.)	23°	1792	35	2500 ±	±2200?
Beds between foot of Great congl. and foot of Greenstone.	23°	1308			4120
	27°	3270?			
Totals.		6370			±6320

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* *Loc. cit.*, map, Pl. XVII.

From these figures we thus find the total thickness of that part of our column at the end of Keweenaw Point, between the top of the Great conglomerate as above determined, and the bottom of the Greenstone, to be 6370 feet, which is practically the same as the thickness of the same zone at Eagle River, as determined by Marvine. But, inasmuch as the Great conglomerate, as above delimited,* is between 400 and 700 feet thinner at the end of Keweenaw Point than at either of the other points mentioned, the zone below it to the bottom of the Greenstone, *on our assumed dip of 27°*, must therefore be almost as many hundred feet thicker there than elsewhere. We are thus assured that unless the latter zone is in reality much thicker at the end of Keweenaw Point than further west, for which there is no evidence, the assumed dip of 27° for that zone is if anything too steep, and that the flat dips noticed at the end of the Point probably extend nearly if not quite as far down as the Greenstone. Thus we are enabled to assume, with a strong degree of probability, that the dips are similarly disposed in the overlying beds both east and west of the Bare Hill core, and that if the average dip for the zone under the Great conglomerate be in reality less than assumed (27°) the thickness of that zone is in fact less than as above computed.

On reference to the map, Plate IV, it will be seen that in the Schlatter Lake area at the extremity of Keweenaw Point, within the zone hitherto known as the Lake Shore trap, there is a conglomerate which I have designated as the Middle conglomerate. On old maps this bed is represented as rapidly wedging out on the west, but the same maps† mark a conglomerate in similar position south of Eagle River. The interval between this bed and the Great conglomerate at points still further south is indicated by a well marked depression. Beginning near the end of Keweenaw Point one can follow westward a similar depression, even more marked, between conglomerate ridges that, as above stated, have heretofore been considered parts of the Great conglomerate. This is the valley down into which the county road to Copper Harbor descends just before reaching the village of that name, and is the same depression in which lie lakes Fanny Hooe, Upson and Bailey. Were not this topographic feature so striking, the relations of the conglomerate and trap beds at the end of the Point might alone suggest a trap horizon along this depression, but the inference becomes a certainty by the observation by Messrs. R. T. Mason and C. F. Moore of a bed or beds of melaphyre in the deep valley just west of Copper Harbor. The outcrops of melaphyre seen here at distances a mile apart, east and west, are near the southern base of the north conglomerate ridge—"Brockway's Nose"—and undoubtedly mark the continuation of similarly placed beds observed at the end of the Point. The "Middle" conglomerate is then the same as the bed north of Lake Fanny Hooe, and the Lower Lake Shore trap under this lake, from its more feeble resistance to erosion, has been degraded more rapidly than the overlying and underlying conglomerates.

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* I. e., including the Lower Lake Shore trap and the Middle conglomerate.

† Stevens, Hill and Williams's, and Irving's.

Under the waters of Lake Superior opposite Eagle River there is a reef which by general consent is held to be trap. I have met with no statement by any one that has actually seen a sample from this reef, and if the latter should prove not to be trap, it would in that case probably be the continuation of the Middle conglomerate.

For the apparent rapid decrease in thickness of the Great conglomerate eastward from Copper Harbor—some 400 to 700 feet in 7 miles—two explanations are possible, either (1) that when the conglomerate first began to form, the land where the end of Keweenaw Point now is was not submerged, or, (2) that the conglomerate as it goes east recedes from the old shore line against which it was laid down, and from which it has since been eroded. It is only necessary to bear in mind, as already pointed out, that in general a conglomerate is thicker near the shore (but not of necessity immediately next to it) from which it derives its material, and grows thinner towards deeper water, where it may also gradually change into sediment of a finer character. If, therefore, we find a heavy conglomerate outcrop preserving the same thickness for miles, we may assume that the line of outcrop is substantially parallel to the original shore line on which the conglomerate was formed, but if the outcrop over long distances shows a regular and progressive decrease in thickness, we may assume that in following it we may possibly be going from the original shore line towards the deeper parts of the original basin. Under this assumption, were the eroded edges of the Great conglomerate and its underlying beds restored, we should probably see the former increased to its normal thickness, and much nearer the east flank of the Greenstone range, thus restoring also, in a measure, the eroded symmetry of the Bare Hill complex. Such a thickening of the conglomerate might be assumed without increasing the total thickness of the combined formations, for we have seen that the calculated thickness of the underlying zone may have been too great by the assumption of too steep a dip.

From the above considerations we have an alternative hypothesis. (1) that an intrusion near Bare Hill may have lifted the later of the Keweenawan strata and bowed them, or, (2) that some of these strata may have been laid down more or less symmetrically around a pre-existing eminence at that point.

§ 10. Bohemia conglomerate west of Mt. Houghton.

West of Mt. Houghton the Bohemia conglomerate, as previously noted, is first seen in an outcrop at about 697 paces N., 1076 paces W., Sec. 23, T. 58, R. 29, about 190 paces north of the brecciated zone that marks the boundary between the Mt. Houghton felsite and the underlying porphyrite. Immediately underlying the conglomerate here is the coarse grained melaphyre belt, which is thus seen to have increased in thickness from the east. Along the west line of Secs. 22 and 27, north of Paddy pond in the same township, both the conglomerate and the underlying doleritic rock are still thicker, the former being apparently 80 paces wide, and the latter about 200 paces wide, but consisting of two beds; the upper coarse grained, and the lower a basic porphyrite resembling fragments in the breccia further east. Under the latter porphyrite and separated from it by a thin layer of conglomeratic material, is the porphyrite that we have followed from the Little Montreal River. This bed here is about 100 paces wide. A north and south fault may run along the stream that empties into Paddy pond from the north, throwing the west side slightly north. The felsite porphyrite does not appear to occur here. In fact, from here westward this felsite porphyrite, or a similar rock, is seen only in the neighborhood of Gratiot bluff.

The doleritic belt under the Bohemia conglomerate continues to increase in width westward, being 300 paces wide in Secs. 27 and 34, T. 58, R. 30, north of Gratiot bluff. In the next section west, Sec. 33, the conglomerate is seen in low ground at 738 paces N., 925 paces W. The underlying doleritic belt is here about 330 paces wide, underlain by the porphyrite, and at 580 paces N., 1925 paces W., in Sec. 31, T. 58, R. 30, seems to have developed into or to be replaced by a coarse ophite. Careful search along the limits of this bed failed to disclose further outcrops of the conglomerate, and the fact that the latter was growing narrower where last seen and the underlying doleritic belt wider, makes the conclusion probable or at least plausible. that the conglomerate has wedged out along the flanks of the massive ophite, which in this area probably rose above the sea in which the conglomerate was laid down, turning the course of the conglomerate northward, where its edge probably lies concealed below the surface under overlapping beds. That this explanation probably accounts for the disappearance of the conglomerate at the surface is strengthened by the analogy of the Kearsarge conglomerate, as will appear more fully when we come to speak of the Central mine, two miles to the northwest.

The beds of the Bohemia belt immediately under the last named ophite are easily traceable southwest into Sec. 9, T. 57, R. 31, where they still form the crest of the Bohemian Range, which here appears to reach its highest elevation, some 900 feet above Lake Superior. The ridge falls away rapidly from here southwest and merges into a more or less drift-covered plateau. Between the above point and Sec. 30, T. 56, R. 32, nine miles south and eight miles west, probably on account of the heavy drift-covering, no beds other than a conglomerate have been noticed by the Survey that appear to be the continuation of the great Bohemia belt. In Sec. 30, T. 56, R. 32, there come to the surface acid rocks which if not the counterpart of those of the Bohemian Range, seem at least to mark the same horizon. These rocks will be referred to later.

§ 11. Lac la Belle conglomerate.

In the diagram of Bare Hill (Pl. V) the conglomerate cut off by the felsite at the southwest is only about 8 paces wide and is made up largely of rounded pebbles of medium acid and of basic rocks. As already noted, it dips about 80° to the north and strikes about N. 75° E. About half a mile west, in the adjoining Sec. 30, two similar conglomerates are exposed in the face of the vertical shore cliff, the upper one being here only about 2½ feet thick and separated from the lower, which is thicker, by a bed 10 to 12 paces wide (about 25 feet thick) of melaphyre so chloritic and slickensided as to be almost unrecognizable as such. The latter also contains numerous seams of epidote. These beds dip at 69° to 71° N. and strike N. 84° E., i. e., directly towards the conglomerate at Bare Hill, last above mentioned. Further west in the bed of the brook that flows through the west part of the same section, the same beds are again exposed, the upper conglomerate being from 3 to 5 feet wide, the melaphyre below it 20 feet wide, and containing seams of epidote nearly a foot wide. The foot of the lower conglomerate is not exposed. In the cliff on the west line of the same section the same beds occur again. These conglomerate beds are cut out about 70 paces west of the point last above mentioned, by acid rocks,* but seem to appear again 250 paces further west. The several conglomerate outcrops above traced are all in the line of strike with two similar conglomerates further west in Sec. 25, T. 58, R. 29, where they form the face of a cliff at least 120 feet high, that almost overhangs the water of Bête Grise Bay. Going west from the bay, towards Lac la Belle, on the road that skirts the terrace (110 (?) feet high), we find traces of conglomerates in the same general horizon in several streams that flow south. They are well exposed along the south side of Mt. Bohemia, on the terrace 110 feet above lake level. At the Lac la Belle stamp mill two conglomerate beds occur, here thicker than those further east, with an interbedded melaphyre, their character and mode of occurrence being such as to leave little doubt in one's mind that they are identical with the conglomerate horizon just traced from Bare Hill. Between these extreme points the conglomerates are everywhere overlain by the ophite, which is known to be quite thick, being on the west line of Sec. 30, T. 58, R. 29, probably not less than 350 paces wide. From Lac la Belle westward no outcrops of conglomerate were found, until in Sec. 20, T. 57, R. 31, where at 650 paces N., 350 paces W. and at 290 paces N., 990 paces W., ill exposed conglomerates occur, which may be a continuation of one or both of the Lac la

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* See p. 52.

Belle beds. Unless cut out, these beds probably run under the waters of Gratiot Lake.

On the east side of Bare Hill we have seen what may be the lower of these two beds, in a faulted position. Further east, near the Little Montreal River, a conglomerate near the top of the low cliff back of the shore may also be the eastward continuation of this belt, but in this case, since this bed is horizontally much nearer the Bohemia conglomerate than at Bare Hill, the dips north of the latter would have to be flatter than those at the Little Montreal River. Another thin bed of pebble conglomerate is also exposed on the east end of the small bay between the mouth of the river and Fish Cove. (See Pl. IV.)

§ 12. Other conglomerates south of the Bohemia conglomerate. The map of Stevens, Hill and Williams and other old maps mark a higher or younger conglomerate that runs west from Bare Hill, through the centers of Secs. 30, 25, 26, 27 and 28, and wedging out east of Mt. Bohemia. No such bed was noticed by the Survey. A large block of conglomerate near the bed of the brook about 1075 paces N., 400 paces W. in Sec. 27, T. 58, R. 29, may have been taken to indicate the position of a conglomerate bed here, but this block is not in place.

On the point on the lake shore southwest of Bare Hill, Sec. 29, T. 58, R. 28, there is rather a wide bed or rather group of immense fragments of a rather basic conglomerate carrying very few distinctly rounded pebbles, but looking like a shattered and sheared melaphyre, much like a part of the Lac la Belle conglomerate north of the Lac la Belle stamp mill. It dips north. Below it on the east side of the point are several large blocks of a regular pebble conglomerate lying in the water. They dip steeply to the north. They may have been disturbed somewhat or detached, but are approximately in line southwest and northeast. The line runs on the east into the wall of rock on the shore behind some melaphyres that show a slipping nearly vertical towards the lake. It probably does not reappear immediately east of this point, for broken masses of the shore felsite (p. 47) come down to the water's edge at the east end of the shore cliff and appear to rest on melaphyre upon which they have fallen. Going west from this line of conglomerate masses, on the south side of the ledge 30 or 40 paces out in the lake some conglomerate appears, like the melaphyre portion of the conglomerate bed above mentioned. The evidence seems to favor the conclusion either that these conglomerates belong to a different horizon from the pair of conglomerates that run west along the shore cliff, or, what seems more probable and has already been suggested, that they are parts of the Lac la Belle conglomerate broken off and faulted from the line of those beds nearer the top of the cliff.

It thus appears that in the areas heretofore considered we find two horizons of well defined pebble conglomerates,—from half a mile to a mile apart on the surface,—between which a large number of basic conglomerates occur. Associated with the lower horizon—the Lac la Belle conglomerate—one small outcrop of quartz porphyry has been found, that may or may not be a flow interbedded with the traps. Above this horizon the only acid rocks noted are intrusive, until we come near the horizon of the Bohemia conglomerate, where the successive beds show greater acidity and culminate in several outflows of felsite that furnished the material for the thickest conglomerate known on Keweenaw Point below the Great conglomerate.

§ 13. Stannard Rock.

That there is thus low down in the Keweenaw series a well characterized horizon of acid rocks, original and secondary, in which the former are extrusive, and that this horizon has a considerable lateral extent is beyond question. That there is a similar horizon near the top of the series in the Rockland district is also well known. The occurrence of original acid rocks elsewhere in the series, rocks that are now recognized as intrusive, leaves open the classification of other acid rocks as extrusive or intrusive, according to the evidence that may govern each case. When, therefore, Irving places the felsite of Stannard Rock (a submerged reef in Lake Superior about 29 miles southeast of Keweenaw Point) in the same "belt" as Mt. Houghton, "or rather as belonging near the same general horizon,"* this cannot be taken as conclusive evidence of the interbedded nature of this rock. A contour sheet (Pl. VI), constructed from Chart No. 2, Survey of the North and Northwestern Lakes,† shows the configuration of the lake bottom southeast from the end of Keweenaw Point to Stannard Rock. The reef of which the latter is the highest part appears as a steep north and south ridge about eight miles long and from one to three miles wide, sharply separated from Keweenaw Point by a valley some 400 feet deep and eight miles broad. That this reef may represent an independent focus of eruption, or perhaps the remains of a mountain around and over which the Keewenaw lavas flowed, thus seems quite as probable as that it once formed an integral part of the Mt. Houghton "belt" or that it "marks for us the course of the Keweenaw Point Range,"* with all that this statement implies.

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* Copper-bearing Rocks of L. S., p. 198.
† Issued by the War Department, Washington.

§ 14. Rocks of Mt. Bohemia.

On the south face of Mt. Bohemia, above the Lac la Belle conglomerate, occur rocks described by Irving as syenite and gabbro and which, so far as observed, are like no other rocks on Keweenaw Point, but resemble many rocks found in place on the Minnesota shore of Lake Superior. The relations of these rocks to the basic flows of the Keweenaw series never have been fully determined; even Irving leaves the matter in doubt, for he says of the augitic syenites and orthoclase-gabbro:

> The former of these two is seen on the upper part of the mountain and its relation to the adjoining rocks was not satisfactorily made out, though it seems more probable that it is intersecting. The other rock shows lower down on the southeast side of the mountain and seems to constitute an interstratified belt (not impossibly an intersecting mass).†

In company with Messrs. A. E. Seaman and W. T. Sutton, the writer, in 1895, spent a day on Mt. Bohemia, tracing on the summit and south face of the mountain the contact of Irving's gabbro-syenite aggregate, the perception of whose relations to the adjoining melaphyres was due to the keenness of Mr. Seaman. The strike of the traps in this vicinity is probably conformable with that of the conglomerate at the south base of the mountain, i. e., slightly north of east, although we had no opportunity to determine the former. The combined gabbro and syenite are thus seen to cut the traps nearly at right angles (Fig. 8). The relations of the two former rocks to each other were not investigated. The augite syenite occurs at the lowest part of the narrow neck, and possibly elsewhere. The rocks at several places on each side of the contact are much altered, and some of them contain a good deal of fibrous hornblende. The conclusion might be drawn that the gabbro has been altered by contact with the massive ophite. The latter then would be the younger rock, and if so, the gabbro-syenite complex would have formed a peak around which the later flows of the Keweenaw series were laid down. Examination of the contact rocks at different points, however, and a study of several thin sections under the microscope by Dr. Lane, lead to the belief that it is the Keweenawan rocks that have undergone the greatest alteration and that the so called gabbro-syenite complex is a deep-seated intrusive in them. This, too, may in turn have been intruded and altered.*

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* Irving, *loc. cit.*, pp. 198, 414.
†*Loc. cit.*, p. 184.

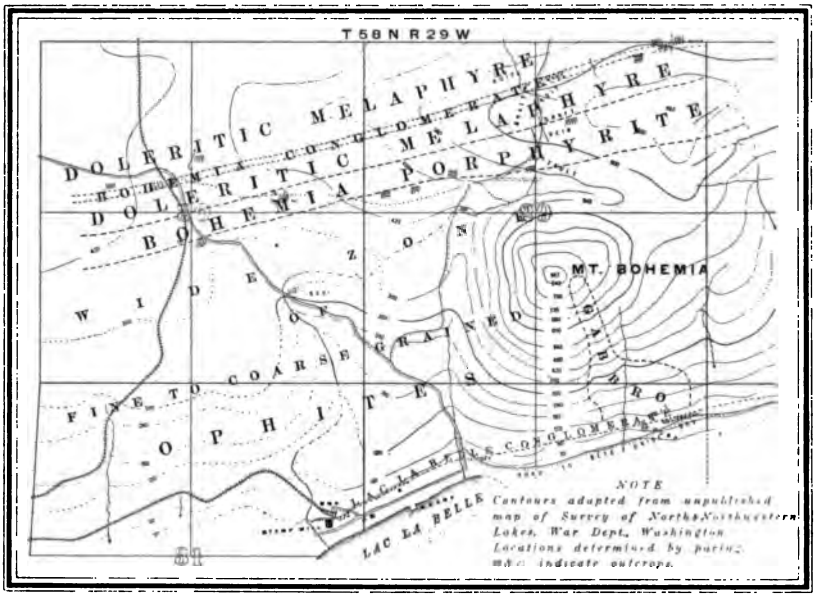

FIG. 8.—Sketch map of the Mt. Bohemia area. Keweenaw Point.

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*Cf. Bayley, The Basic Massive Rocks of the Lake Superior Region. Journal of Geology Vol. I. No. 7. p. 714.

The following notes by Dr. Lane are on the specimens from Mt. Bohemia, Sec. 29, T. 58, R. 29.

S. 16920 from the Keweenawan outside the gabbro, 650 paces N., 900 paces W., is an illustration of a slightly altered melaphyre. The eye cannot recognize the feldspars any more, and instead of the flashing patches of ophitic augite are patches with a satin sheen. The rock has become more uniform in color. Under the microscope the feldspar is seen to be largely changed to sericite, probably mixed with carbonates, epidote and chlorite, though enough is left to show that it was labradorite. The olivine is all gone, and a tendency for idiomorphic magnetites to develop from it can be traced. The augite proves to be still largely present in patches 4 to 8 mm. across and more, but is changing to blue-green hornblende and chlorite. This uralitic alteration of the ophite appears to be due to the gabbro contact. (Rosenbusch iii, pp. 121, 265.)

In S. 16925, close to the contact with the gabbro, 150 paces N., 700 paces W., the change of the augite is complete but the original areas can be distinguished more or less, partly by common orientation of the uralitic hornblende, and—especially when the secondary hornblende fibres are at random—by the relative scarcity and finer grain of the magnetite within these patches—corresponding to the original scarcity and absence of olivine.

S. 17408, from near the north end of the gabbro tongue, and sections like it, are as much altered as the above, but lack the traces of ophitic texture. They have areas with no hornblende and with finer magnetite, which appear to replace feldspar phenocrysts, and are probably from melaphyres of the contact zone which were more decomposed or less characteristic originally.

S. 16923, 450 paces N., 700 paces W., differs from the foregoing in composition and in texture. It is coarser. The texture is that of a plutonic rock, the interstices being filled with clear quartz which occasionally shows traces of granophyric intergrowth with the red-margined feldspar. The feldspar has lower refraction than the quartz, generally it shows low extinction angles, occurs in laths 1 to 2 mm. broad and 4 to 5 long, and is distinctly oligoclase. The hornblende is about equal in quantity to the feldspar and in equally large areas, generally with a uniform orientation, but more or less intermingled with calcite and chlorite. Some of the hornblende is undoubtedly secondary, but waiving the question whether there may not have been some primary hornblende the nature of the feldspar and the character of the texture and relative proportions of the constituents would lead me to class it with Rosenbusch's diorites according to his third edition, pp. 241, 244. It is a type of Irving's orthoclase gabbro. It has not at all the texture of an effusive, but is plutonic in texture with a leaning toward dike texture, and is closely akin to the salite diorite described in the footnote to p. 257, of Part I.

S. 16924, 160 paces N., 600 paces W., which is a brick-red granular rock with a few green specks, is an aplitic facies of 16923, that is, the ferro-magnesian constituents are almost gone. The heavily red clouded idiomorphic oligoclase laths (75% + Ab) are smaller, 0.1--0.3 mm., and shorter. The quartz is in even smaller granules but shows the aplitic tendency to idiomorphism. Rectangular sections with diagonal extinctions are abundant, but we have also traces of granophyric intergrowth with quartz. There are rare altered phenocrysts which may have been pyroxene. This is a dioritic aplite. It is the same type of rock as the red rock of the Duluth gabbro, *i. e.*, U. S. Grant's soda granite, Irving's augite syenite and granitell, and by increase in granophyric character (micro-pegmatite) would become the granophyrite which occurs so abundantly in the Keweenawan conglomerates, e. g., in S. 16983, from the base of Mt. Bohemia.

CHAPTER IV.

OTHER OCCURRENCES OF ACID ROCKS.

§ 1. Curvature of the Greenstone at Eagle River gap.

From the area north of Bare Hill, last under consideration, the course of the Greenstone lies about S. 80° W. for upwards of 15 miles, to a point near Eagle River gap, where it curves rapidly to the south, and after describing to the west another slight curve whose crest is near the Allouez location, it runs, no one knows how far, in a direction varying little from S. 33° W.

The Greenstone belt at Eagle River is upwards of a thousand feet thick. At Allouez gap it is very much thinner and eroded down to within about 225 feet of lake level. Between Allouez (Sec. 31, T. 57, R. 32) and Calumet (Sec. 13, T. 56, R. 33) it is again marked by a ridge, less in contrast, however, with the adjoining areas than further north, and in the shafts of the Tamarack, and Calumet and Hecla mines it appears to be from 190 to 277 feet thick. At the Franklin Junior mine, Sec. 8, T. 55, R. 33, there is no belt above the Allouez conglomerate recognizable by its thickness as the Greenstone, the ophite next under that conglomerate there having, on the contrary, attained to a thickness of about 134 feet.* On Isle Royale it appears to be thicker at the east end than at the west end of the island. Whether regarded as a single bed† or as a group of several beds, it thus evidently filled a north and south depression between a point or points near Eagle River and the North Shore, overflowing on the southwest into another narrower and shallower channel. The crest in the Allouez curve was therefore apparently in existence prior to the Greenstone flow, for the bed at the Allouez resembles the *hanging* of the Greenstone further north.

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*See Plate IX.

†Dr. Lane, after personal examination of the Greenstone at Eagle River gap, believes that it consists of a series of flows that followed one another in such rapid succession as to constitute practically a single bed—a point on which at present I have no opinion to offer. See this volume, Part I, p. 75.

The course of the Greenstone from the Bare Hill area west and southwest as far as Eagle River gap is in accord although not strictly parallel with that of the Bohemian Range, which we have previously traced through Sec. 9, T. 57, R. 31. No intrusive rock masses have been noticed that would account for the curvature of the two ranges at and opposite Eagle River gap, and the structure here may, perhaps, be explained by some other hypothesis—a subject that may best be taken up later.

§ 2. The Allouez curve.

In a reference previously made to the gap near the Allouez mine I have said that the gap marks the southern termination of the Greenstone and Bohemian ranges, and their separation from the broad plateau-like area that extends south to Portage Lake and beyond. This gap also marks the crest of a mass of quartz porphyry, at the bottom of the Keweenaw series as exposed here, near the junction of the latter with the Eastern sandstone. The porphyry, first observed in a small outcrop by Messrs. Seaman and Lane of the Michigan Survey in 1889, was laid bare by the clearing of the land in subsequent years, and is now seen to extend from near the southwest corner of Sec. 4, T. 56, R. 32, diagonally half way across the section, and to be at least 300 paces wide (Pl. VII). The rock is light gray, and where weathered, white. It contains small scattered phenochrysts of light colored feldspar and corroded grains and dihexahedra of quartz in a fine grained groundmass dotted with minute dark colored inclusions (S. 17525).

For some distance south of the Allouez mine the positions and curves of the principal beds between the Allouez conglomerate and the Kearsarge amygdaloid have been accurately determined from surface outcrops and by pits and mine shafts. At Calumet, in Secs. 13 and 23. T. 56, R. 33, these beds maintain an almost parallel course, about N. 33° E., and a northwesterly dip which at the surface varies from about 38° on the Calumet conglomerate at the north end of the Calumet and Hecla mine to 39° on the Allouez conglomerate at the Allouez mine (See note, page 117.) Taking up these beds in order we see, what has already been stated, that the highest conglomerate, the **Allouez,** describes a curve convex towards the west, across the Allouez gap (Sec. 31, T. 57, R. 32). As marked on the map (Pl. VII) this curve appears slightly more accentuated than it really is, owing to the lower altitude of the gap.[*] In Sec. 29, T. 57, R. 32, the strike is about N. 39° E., the dip not measurable with certainty but probably flatter than at the Allouez mine, from which point it probably decreases as we go north. At Eagle River gap it is probably between 26° and 27°.[†]

Omitting the Calumet and the Houghton conglomerates, which are supposed to be in almost strict conformity with the Allouez conglomerate but which have not been found immediately north of the area under discussion, unless it be on the Seneca location, we come to the **Kearsarge conglomerate.** This bed is exposed at the surface on the Kearsarge location, north of the latter in several pits east of the railroad, and at the Ahmeek location, near the east quarter-post of Sec. 32, T. 57, R. 32. At the last named point the strike is about N. 45°-50° E. The dip measured on the shaft stringers is 44½° N. W., these figures being only one-half degree less than the dip as determined by the relation of width (75 ft.) to thickness (52 ft.)[‡] In any event the convexity of the curve of this conglomerate appears to be greater than that of the higher lying Allouez conglomerate. On the hanging of the former bed at the Ahmeek there is a layer of flucean, which, according to Capt. J. C. Hodgson is two feet thick, with the next three feet cupriferous.

The **Kearsarge amygdaloid,** the bed worked at the Kearsarge and Wolverine mines in Secs. 6 and 7, T. 56, R. 32, is at these mines about 1250 feet horizontally southeasterly from the Kearsarge conglomerate, measured at right angles to the strike. In the Kearsarge mine, according to R. M. Edwards, Mining Engineer of the Tamarack Mining Company, the strike of this bed as the latter is followed north curves 5° to the east in the drifts of the mine. Outcrops of the footwall of this bed are well exposed in Sec. 27, T. 57, R. 32, on the Fulton location, where the Kearsarge amygdaloid has been uncovered by several pits near the southwest corner of the section (Pl. VII), and has been shown to be cupriferous[§]. The footwall rock is a thick bed of ophite characterized by large phenocrysts of labradorite. According to the location of these outcrops the bed is found here to be curving rapidly to the west as it is followed south.

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[*] Probably more than 200 feet.

[†] The dip of the "slide" or Allouez conglomerate at the Cliff mine according to Hulbert and Lum (1857) is 24°, according to P. H. Updegraff (1870) between 24° and 25°. The Cliff mine is about two miles south of Eagle River gap.

[‡] Capt. J. C. Hodgson. This dip seems abnormally steep for this point.

[§] This property is now known as the Mohawk mine.

Underlying the Wolverine ophite is a bed of **Sandstone** mapped by Marvine and Ladd,[*] and also mentioned by Rominger.[†] According to Capt. Hodgson this bed, 265 feet east of the Kearsarge amygdaloid, is an altered conglomerate, chiefly of dark colored sandstone, 40 feet wide, with 2 feet of fluccan on the footwall. So far as known to the writer, no outcrops of this sandstone have been noted elsewhere in this immediate area. It may correspond to Marvine's conglomerate No. 9 exposed (?) near Portage Lake. It may at other points be an amygdaloid conglomerate. A large boulder of such a conglomerate lies by the roadside in the hollow east of the line of the bed in Sec. 7, T. 56, R. 32.

East of the Wolverine mine (about 950 paces, measured east on the north line of Secs. 7 and 8, T. 56, R. 32), there is exposed for several hundred paces in a low ridge an outcrop of a rather light colored melaphyre containing numerous apparent inclusions, of amygdaloidal character, that carry calcite. This bed strongly resembles the footwall of the Isle Royale cupriferous bed back of Houghton, as well as another bed about 400 paces above it on the old Huron location[‡] (Sec. 2, T. 54, R. 34). With an average dip of 46° for the intervening strata (which I am inclined to believe is too steep), it is 1521 feet vertically below the Kearsarge amygdaloid—a measurement that is some 700 feet less than the vertical distance between the position of the supposed Kearsarge amygdaloid at the Franklin Junior and the Douglass-Arcadian (Isle Royale) bed east of it.[§] The same bed outcrops in two places about 15 paces apart on the Fulton location, at about 375 paces north, 490 paces west, Sec. 27, T. 57, R. 32. (See Pl. VII.) Just beneath it here is a dark brown crumbly ophite the lower part of which, or the next lower bed, carries large amygdules of stellar quartz. Next above the bed with inclusions is another dark brown decomposed ophite. At the point first indicated, east of the Wolverine mine, the light colored, "inclusion" bed strikes N. 38°-40° E. and dips N. W. about 50°—possibly less— and here, as at the Fulton location, is overlain and underlain respectively by darker, brown colored ophites, that are crumbly towards their hanging walls. The course of this bed as indicated by the two sets of outcrops, shows a close conformity with the higher beds previously described and must run very near—possibly to the west of—the old workings of the Forsyth mine, near the south quarter-post of Sec. 33, T. 57, R. 32. Beneath the "inclusion" bed occur alternations of amygdaloids and very coarse grained or doleritic melaphyres, well exposed on Sec. 4, T. 56, R. 32. They carry more or less quartz in amygdules and show considerable epidote, points of resemblance with beds above and beds below the Arcadian-Isle Royale horizon at Portage Lake.

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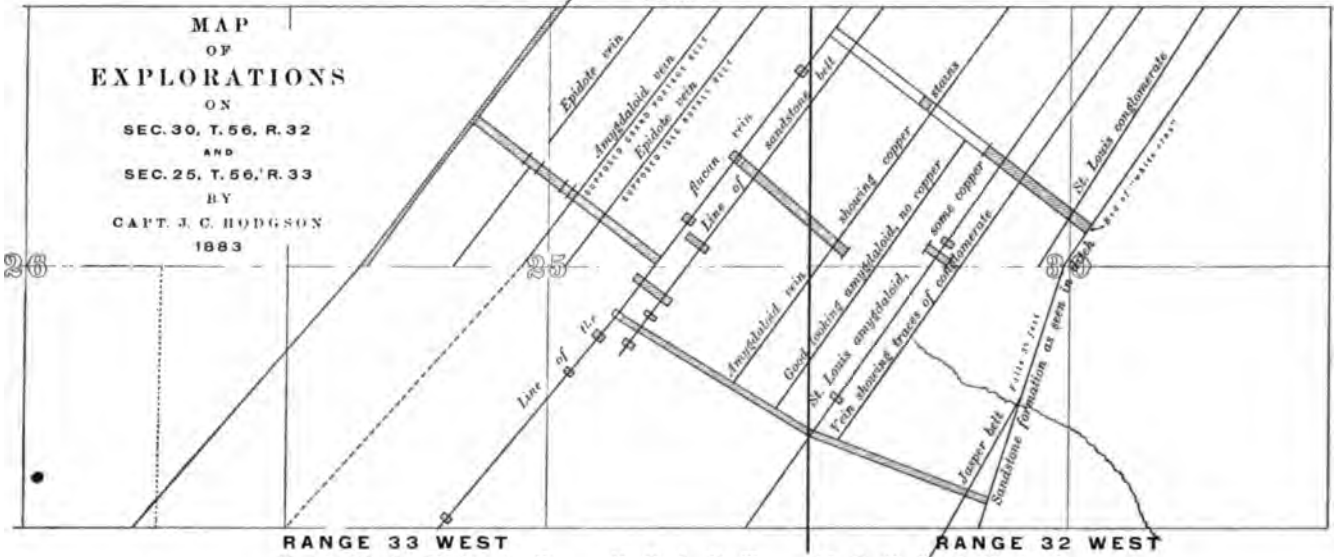
[*] Geol. Sur. Mich., I. Atlas, Pl. XIX. No. 9. Gray slaty sandstone and fine red sandstone.
[†] *Ibid.*, V, Pt. I, p. 118.
[‡] Other similar beds have been noted lower in the series, south of Portage Lake.
[§] See Chapter VI and Plate IX.

At the base of these beds we find a rather wide bed of a very tough and very coarse grained basic rock that merges on the southeast or footwall side into a coarse ophite, immediately beneath which—between it and the quartz porphyry—is a **conglomerate**, exposed at short intervals between the southeast corner of Sec. 5, T. 56, R. 32, in low ground, and a point in Sec. 4, about 1125 paces north, 525 paces west, of the southeast corner. This bed strikes uniformly about N. 55° E. and dips N. W. 58°. At its most southerly exposure in Sec. 5, however, the strike appears to be N. 50° E., and the dip about N. W. 70°. In Sec. 35 in the next township north, a similar conglomerate is exposed at 1425 paces north 1235 paces west in a prominent knob, here underlain by a coarse grained melaphyre like that under the Bohemia conglomerate further east. This outcrop, it will be observed, is only slightly east of the direct line of apparent strike of the conglomerate in Sec. 4, which is some 200 feet lower. The latter bed is about 24 paces wide at its greatest exposure and may be still wider, for there is a covered space of 100 to 150 paces between it and the underlying porphyry. It carries rounded to angular fragments—some as large as a man's head—predominatingly of acid rocks of felsitic or of porphyritic structure, quite dark colored, containing phenocrysts of red feldspar and much like the Praysville porphyry. There is very little matrix present at some points, other than calcite; at other points the matrix is coarse. One fragment of the felsitic kind showed spherulites.

A. Identity of the St. Louis conglomerate with the conglomerate of Sec. 4, T. 56, R. 32.

In the next section southwest, Sec. 8, T. 56, R. 32, the land rises rather rapidly some 200 feet from the valley of the Trap Rock River, whose west branch here flows southeast through the northeast quarter of the section. Massive outcrops, often in rounded knobs, of rocks similar to the belt noticed in Sec. 4 above the conglomerate, appear in a broad plateau which falls off to the east abruptly in places, for three-fourths of the way south through Sec. 8. On the edge of this plateau at about 750 paces N., 865 paces W. is a knob of very coarse grained rock, which over small areas shows a distinctly ophitic structure. This rock very closely resembles that of the nearest exposed bed above the conglomerate in Sec. 4. Careful search failed to find rock east of it where it is exposed in Sec. 8, except in a line of pits that extend a hundred paces to the east, a heavy deposit of drift material lying over them. Basic rocks had probably been found in some of these pits. There are also indications that the Eastern sandstone is probably in place near here, under the drift. In Sec. 17, next south, however, at 1600 paces north, 1025 paces west, in a ravine, a conglomerate bed is in place that closely resembles the so called **St. Louis conglomerate** which has been traced through Secs. 20, 19 and 30, southwesterly. An extensive group of large fragments of the same conglomerate was found in Sec. 17, about 900 paces N., 1325 paces W., which occurrence makes it fairly presumable that the course of the St. Louis conglomerate in this section is slightly east of north, and that the St. Louis conglomerate and the bed in Sec. 4 are one and the same bed. This conclusion is rendered still more probable by the occurrence at 874 paces N., 134 paces W., Sec. 19, T. 56, R. 32, of a very coarse grained and ophitic rock (Sp. 17538), like the bed immediately above the horizon of the latter conglomerate, already twice described, once from Sec. 4 and again from Sec. 8, T. 56, R. 32. Here this bed is exposed about 140 paces horizontally above the conglomerate; the dip is growing flatter as we go south. Although the St. Louis conglomerate in Sec. 20 (Wall Ravine) and further south contains some pebbles that are fairly large, most of its fragments are small and many are subangular to very angular, much resembling a tuff, this being a very

FIG. 9


TOWNSHIP 56 NORTH
26
25
30
Epidote vein
Amygdaloid vein
SUPPOSED GRAND PORTAGE BELT
Epidote vein
SUPPOSED ISLE ROYALE BELT
Line of fluxan vein
Line of sandstone belt
Line of the
Amygdaloid vein, showing copper stains
Good looking amygdaloid, no copper
St. Louis amygdaloid, some copper
Vein showing traces of conglomerate
St. Louis conglomerate
End of "white clay"
Sandstone formation as seen in creek
Falls 35 feet
Jasper belt
RANGE 33 WEST
RANGE 32 WEST

MAP
OF
EXPLORATIONS
ON
SEC. 30, T. 56, R. 32
AND
SEC. 25, T. 56, R. 33
BY
CAPT. J. C. HODGSON
1883

KEWEENAW POINT, MICHIGAN

characteristic feature of this bed along here and indicating proximity to the bed or beds from which its material was derived. The matrix is rather coarse and fairly abundant, and many of the pebbles resemble the porphyrite of the Bohemian Range, being less porphyritic than the Praysville porphyry. The rock, so far as pebbles and matrix are concerned, is firmly coherent, but is much jointed.

In the appended diagram, Figure 9, are given the results of trenching done under the superintendence of Capt. J. C. Hodgson, to whose kindness I am indebted for the sketch from which the diagram was copied as well as for much other information. It shows the course of the beds at this point, and the occurrence of sandstone and conglomerate higher in the series, but what is the nature of these beds, I am not informed.

On Plate XIX, published with Vol. I, Geological Survey of Michigan, a cross-section at the Kearsarge mine, by Marvine and Ladd, shows three conglomerate beds and a bed of "jasper" east of the Wolverine sandstone which are stated to have been scaled from a small map made by Capt. William Newcombe. The position of the most easterly of these beds on the cross-section and its identity are queried. The other beds (Nos. 4, 5 and 6 of Marvine's Portage Lake conglomerates) are horizontally 3598, 3298 and 2930 feet, respectively, from the Wolverine sandstone and would fall within the zone occupied by the belt of coarse grained rocks above the horizon of the St. Louis conglomerate, but none of them has been seen by the present members of the Survey, and they do not appear, from the measurements above given, to correspond to the beds located by Capt. Hodgson.

B. Relations of beds.

Plate VII shows a horizontal section, approximately correct, of the beds above described. We see at the base of the section, arching over a mass of quartz porphyry, a conglomerate which dips 70°-58° and strikes from about due north on the south side of the arch to N. 55° E. on the north side. Up to the horizon of the Greenstone each successive bed on which observations were made shows a gradually decreasing dip and perhaps less divergence in its strikes, on the two sides of the arch. This divergence, however, is still quite marked as far up as the Kearsarge conglomerate. That the dip of each individual bed also flattens—to the north, at least—is probably also true; the amount of decrease—if any—south for the higher beds is comparatively small.

The above relations of the several beds make difficult any very positive conclusion as to the cause of the rapid change of strike. The porphyry may be intrusive. Pebbles from the overlying conglomerate resemble it, but they are not thought to be abundant enough or scarce enough to serve as an argument either way. If the porphyry is intrusive, it is probably older than the Greenstone, if, as should seem natural, it was the cause of the ridge in the lower strata that separates the two lateral extensions of the Greenstone north and south of Allouez gap (p. 74). In this case we should expect to find in the immediate vicinity of the porphyry evidences of disturbance in a faulting of the overlying beds. Only one such fault* is known in the vicinity—the Seneca fault—between the Seneca location (Sec. 29, T. 57, R. 32) and Forsyth Hill and possibly extending southeast of the latter. This fault, however, is supposed also to cross the Greenstone, but cannot have caused any marked dislocation there. Little is known about it, but if it does cross the formation and was caused by the intrusion of the porphyry, the latter would then be younger than the Greenstone.

At the Allouez mine two fissures cross the formation, one of which shows two or three feet of fluccan, but neither seems to be accompanied by any heave in the adjoining beds.

On the other hand, the curvature of the overlying beds is such that they might have been laid down over the sloping sides of the porphyry, and subsequently tilted, as discussed in the preceding chapter. If reduced to lake level the curves of the different beds would not appear as marked as in Plate VII, so that it is not inconceivable that the same or similar lava sheets may have flowed over a flat conical projection of porphyry and arranged themselves as we now see these beds. There is apparently no flexure of the overlying beds immediately south of the porphyry. As above remarked, no contact is visible between the porphyry and the underlying conglomerate, but at Wall Ravine the St. Louis conglomerate, near its *hanging*, is found in contact with a mass of decomposed porphyry, and Capt. Hodgson found in the next section southwest of Wall Ravine, 50 feet or more *below* the conglomerate, a bed of "white clay," evidently the kaolinized decomposition product of a porphyry.* If this is a product of slide-faulting, like much of the fine material we find along the contact of the traps and Eastern sandstone, we may be right in refusing to assign to this porphyry an intrusive character. If it is older than the overlying beds, it may even belong to an older series.

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*This fault—"vein"—is said to strike N. 22° W.

§ 3. Identity of the Bohemia and St. Louis conglomerates.

The beds from the Greenstone to the St. Louis conglomerate, as we have just seen, disclose a more or less increasingly easterly strike, towards the north across the Allouez gap. The Greenstone and the Kearsarge amygdaloid on the Fulton location soon begin to swing back, more towards the north. In an unpublished cross-section of beds at the Cliff mine, by F. Klepetko, we find three conglomerates approximately at the same distance from one another, in which the Allouez, Calumet and Kearsarge conglomerates occur between Calumet and the Allouez mine.† In other words, they have followed the Greenstone in its curving back towards the north. The same relative position of the above conglomerate beds is also found to be true in the Central mine. It is thus a matter of fairly strong inference, that the St. Louis conglomerate, in like manner with the higher conglomerates, must swing to the north from its last observed outcrop in Sec. 35, T. 57, R. 32, and that its course must curve in harmony with theirs, passing west of the ophite that caps the Bohemia belt, where the latter appears along the crest of the Bohemian Range in Sec. 9 of the township next east. This conglomerate bed may here wedge out or be overlapped by higher beds, as was supposed to be the case with the Bohemia conglomerate further northeast. It is thus apparent that the St. Louis conglomerate and the Bohemia conglomerate must eventually approach the same horizon. Their characters, their position with reference to other horizons, and the absence of other conglomerates near each of them in areas where they are separately exposed may justify us in the conclusion that they are in all probability one and the same bed.

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*Between these two points there are trap rocks 200 paces in width below the conglomerate, but the porphyry may intervene.

†The Houghton conglomerate is not positively known to occur in the Calumet and Tamarack mine shafts.

§ 4. Conglomerates exposed in the Central mine.

The Central mine, in the south half of Sec. 23, T. 58, R. 31, close under the Greenstone, is in a fissure vein that strikes N. 13° 07′ W. and hades vertically from the surface to the 9th level—nearly 700 feet. From the latter point the apparent hade* of the vein averages about 7° 42′ east, to the conglomerate bed found near the bottom of the mine, or including the vertical part of the vein its average apparent hade from the surface is 5° 27′.†

Four conglomerate beds are encountered in this mine at vertical distances that correspond with the four conglomerates next below the Greenstone near the Allouez gap.

It thus appears that the lowest conglomerate is the Kearsarge, with whose character at Calumet, on the Kearsarge location and at the Ahmeek location it here also agrees, except that its pebbles show less porphyritic feldspar. It is composed largely of pebbles of varying size, of a hard brownish rock, in whose aphanitic groundmass there is much quartz in large grains or crystals. These pebbles lie in a cement of similar material, and near its footwall in several places the texture of the rock is so fine as hardly to be recognizable to the naked eye as conglomerate, but resembles rather that of a bed of compact quartz porphyry. This may be due to a crushing of large masses of the enclosed rock. Similar phenomena occur in conglomerate bed No. 7 (Marvine, Geol. Sur. Mich. I, Atlas, Pl. XIVa) on the south side of Portage Lake, which, according to Capt. J. C. Hodgson runs into a bed of "jasper" on the north side of the lake.

§ 5. Flattening of dips vertically.

On Pumpelly's cross-section of the Central mine (*Ibid*, Pl. XXIII) the beds show a general decrease of dip from south to north. Measurements by the writer in the lowest levels of the mine, near the Kearsarge conglomerate, show that the dip along the top of this bed decreases, in a distance of 500 to 600 feet, from about 27° at the south or higher end of the bed, to about 21° at the lowest part of the bed exposed in the mine. It also appears that this conglomerate bed is a mere seam of sandstone in the mine near the 27th level, its thickness increasing gradually from that point downwards until in the 32nd level—about 1300 feet on the slope—it is 57 feet. A similar wedging out, it will be remembered, was suspected to occur in the Bohemia conglomerate, southeast of this place. This difference of 6° in curvature of the top of the conglomerate may be due to the fact that we are here at the rim of the basin in which the conglomerate was laid down. In those parts of such a basin that are nearer its center, or farther from its rim, the dip of the conglomerate probably represents its true niveau or relationship to other conglomerate horizons in the same series, more nearly than do parts of the conglomerate near its margin, and in the present case the dip of 21° establishes a flatter niveau for the lower beds of the series than for overlying horizons which near the surface, in this area, both south of the Greenstone and for a mile or more north of it, have a well established dip of between 26° and 27°. This observation, so far as it goes, is important. If it should be found to be generally applicable throughout the Keweenaw series, it would tend to negative the assumption of a gradual differential subsidence of those parts of the beds nearest the central parts of the Lake Superior basin, during the formation of later overlying beds, for in the latter case the lower beds would dip *more steeply* than those parts of the higher ones, that were originally vertically above the former, or if the subsidence took place by the simultaneous and equal sinking of large areas, the successive conglomerate beds, other things being equal, would be *parallel*. The relations actually observed are, on the contrary, quite in harmony (1) with the general effect of an uplifting agency acting on the south side of Keweenaw Point, or (2) with the deposition of beds on a gradually decreasing slope.

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*Measured in a plane that cuts the plane of the vein at an angle of 86° 42′. The hade, underlie or underlay of a vein, is its inclination from the vertical—the complement of the dip. This explanation may seem superfluous, but the two terms, hade and dip, have recently been used as synonymous.

†See paper on "The Relation of the Vein at the Central mine, Keweenaw Point, to the Kearsarge Conglomerate", Proc. L. S. Min. Inst., 1895.

§ 6. So called Kingston conglomerate.

Marvine records an outcrop of a conglomerate 45 feet wide, 500 feet south of the center of Sec. 33, T. 58, R. 31.* He recognized the similarity of this bed in character to the Kearsarge conglomerate, further south, but on an assumed average dip of 28° between the Greenstone and the point of exposure, 5870* feet horizontally, he figured that this bed must lie 600-700 feet east of the Kearsarge. He says that if the dip were about 25° it would be the same bed as the Kearsarge. Now, with a dip of 26°, the vertical distance between the Greenstone and the "Kingston" is only 2573 feet, as against 2599 feet between the Greenstone and the Kearsarge in the Central mine. At the Cliff mine, about 2½ miles southwest, the Kearsarge conglomerate is according to Klepetko 40 feet thick, and horizontal and vertical measurements between beds there, made on Klepetko's cross-section, show that the assumed dip of the formation there is less than 26°. As I have already noted, the dip of the "slide" under the Greenstone at the Cliff mine is about 24°.† Marvine says that along a line between Eagle River village and the Phoenix mine, near the Greenstone, the dips decrease, coming south,‡ i. e., towards the lower beds of the formation.

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*Geol. Sur. Mich. I. Pt. II. p. 114 In Marvine's description the township is erroneously printed as T. 57, and in Irving's the location is given as 500 paces south of the center of Sec. 37, T. 57, (Copper-Bearing Rocks of L. S., p. 176).

We have just seen that in the Central mine, less than three miles northeast from the "Kingston" conglomerate, we find the Kearsarge conglomerate showing, where thickest, a dip of 21°. From the foregoing indications it is probable that Marvine, and Irving after him, assumed too steep a dip for the strata opposite and east of Eagle River gap, which resulted in making the estimates there too thick and in confounding the Kearsarge conglomerate with a bed which Marvine supposed lay east of it. It seems, therefore, no longer a question of doubt, that the so called Kingston conglomerate is not an independent bed, and as such must henceforth be dropped from the list of conglomerates.

§ 7. Fault in the Central mine.

The top of the Kearsarge conglomerate in the Central mine marks the bottom of the so called east vein, where the latter has evidently been faulted to the east above the conglomerate. What was formerly the downward continuation of this vein is found penetrating upwards to the hanging of the conglomerate at a point farther west which would make the amount of heave of the vein 284 feet.

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*Irving makes the distance 4650 feet, but this must surely be another typographical error for he would have no motive to remeasure the distance.

†See foot note, p. 76.

‡*Loc. cit.*, p. 96.

The upper part of the formation west of the vein is also thrown about 35 feet north.[*]

The top of the Kearsarge conglomerate is in places for three or four feet down much decomposed, and altered to epidote, calcite and prehnite—an alteration that seems to be more general at points where there are numerous indications of fissuring and brecciation of the conglomerate. Above this bed is generally found a layer of fluccan, reddish clayey material, sometimes hard and compact, but usually moist and soft, and in places containing small ellipsoidal[†] forms as of pebbles, which also seem to be of similar decomposed character to the clay that encloses them. Above this clayey material is a bed of blacker brecciated material, very fine and chloritic near the fluccan, but growing coarser towards its upper side where it merges gradually into a bed of compact ophite. This breccia bed is in many places 10 to 15 feet thick, and together with the faulting of the vein is evidence that there has been a shearing movement or slide-faulting along the upper surface of the conglomerate. The strike and dip of the conglomerate and the strike of the vein being known, it is possible to compute the amount of sliding down the conglomerate in the direction of greatest dip, necessary to produce the given amount of heave of the vein. This is one of only two cases,[‡] so far as known to the writer, where the posssible amount of sliding along beds of the Keweenaw series can be established, and in view of the probable prevalence of this phenomenon throughout the series, and its intimate connection with the structure of Keweenaw Point, a somewhat detailed discussion may not be out of place, although it might more properly belong in a later chapter.

§ 8. Slide-faulting on the Kearsarge conglomerate.

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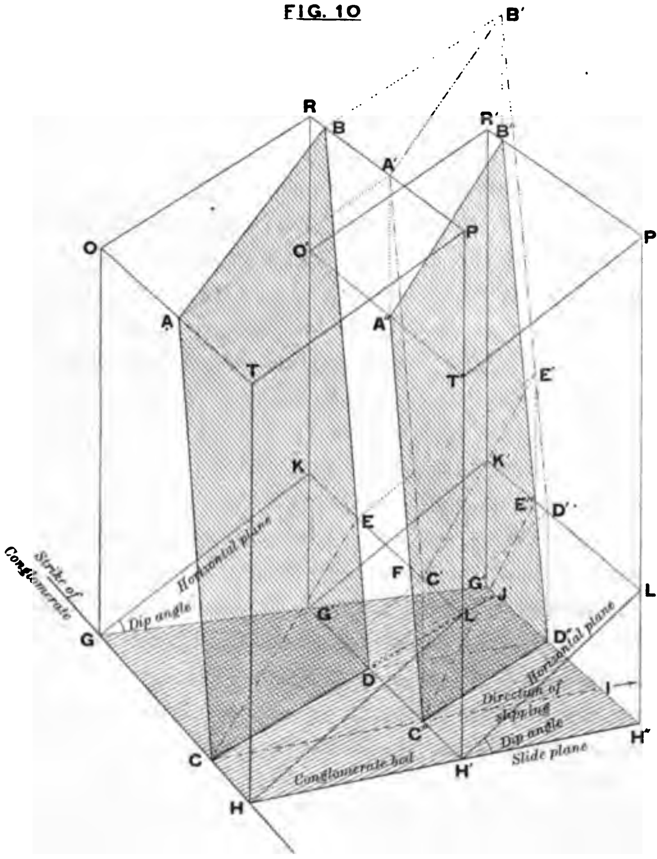
[*] In the article above referred to (p. 102), I thought from an inspection of the west level that the ground west of the west vein had been faulted downwards, but later work by the miners showed the rock west of the vein in the 30th level to be a porphyrite, like the bed under the conglomerate. This would make the throw on this side up instead of down.

[†] This phenomenon is very common along slide-faults on Keweenaw Point, especially between the traps and the eastern sandstone. See discussion by N. H. Winchell, Geol. and Nat. Hist. Sur., Minn., 23rd Ann. Rep., p. 15.

[‡] The other case is that of the Armstrong vein at Eagle River, where Marvine computed a fault of 150 feet, Geol. Sur. Mich., I, Pt. II, p. 128. He does not give the data on which his computation is based.

In order to represent the conditions noted in the Central mine, let A B D C, in Figure 10, represent a vein dipping to the right, or east, and extending downwards through a bed G H G″ H″ at C D. Let G H, a horizontal line, represent the strike of this bed, and G H K L a horizontal plane cut by the vein along C E, which latter is thus the direction of the strike of the vein. The angles K G G′ and C′ C C″ will represent the dip of the bed G H G″ H″; the angle T A C the dip of the vein; the horizontal angle E C C′ the amount of differ-

FIG. 10



To determine the amount of slide-faulting along a tilted bed, necessary to effect a certain amount of heave in a vein cutting that bed.

ence between the direction of strike of the vein, and the "dip-plane" of the bed G H G″ H″, which is at right angles to the strike of the bed, and may be represented by the plane C′ C C″, or any plane parallel to it.

If we imagine a block of "ground" OH′RH as sliding down the plane of the bed GHG″H″, in the direction of steepest inclination, i. e., of its "dip-plane," CC″I, this block will come to rest at O′H″R′H′, and the vein *above* the bed will assume the position A″B″D″C″. C″D will then represent the distance apart of the original and new positions of the vein measured along the strike of the bed GHG″H″, a measure which we may here, for convenience, call the "lateral displacement" of the vein. If this line, C″D, were at right angles to the plane of the vein, ABCD, it would represent the true heave of the vein. The smaller the angle DCC″, the more nearly do the amount of heave and the "lateral displacement" coincide. CD and C″D″ represent the two intersections of the vein with the slide-plane. If C″D, and the angles C′CC″ (the dip of the bed GHG″H″) and TAC=ACG (dip of the vein) are known, we can determine CC″, i. e., the amount of slipping or slide-faulting, CI, necessary to produce a lateral displacement equal to C″D.

On the principle of the parallelogram of forces, the motion of the block down the slide-plane may be resolved into two motions, one horizontal and the other vertical. The points C, A, and B may be considered as moving first to C′A′ and B′ respectively, and thence to C″, A″ and B″ respectively. The vein would then theoretically first assume the position A′B′D′C′, and would then have a lateral displacement represented by C′E. In moving vertically downwards, however, owing to its eastward dip the vein again approaches its line of intersection with the conglomerate further north, or reduces the amount of the lateral displacement gained by its horizontal movement. It cannot altogether overcome the displacement when the dip of the vein in the direction of the dip of the conglomerate is steeper than that of the conglomerate. The effect of a dip of the vein may best be appreciated by following the point C in its assumed movement to C′ and then to C″. Between C and C′ it is constantly going further from the original plane of the vein, but from C′ to C″ it again approaches the original position of the plane of the vein, but (in the case in hand) at a slower rate. During the latter movement it loses an amount represented by C′F.

In order to ascertain the amount of sliding necessary to produce a given displacement, we must determine:—

1. The amount of horizontal movement, x, along CC′, necessary to gain one foot laterally in the direction EC′.

2. The amount of lateral displacement, y, lost for every foot of vertical movement along C′C″.

y = tan hade of vein.

3. (a) The amount of vertical movement, z, corresponding to the horizontal movement, x.

This depends altogether on the dip of the slide-plane, and equals x times tan dip of slide-plane.

(b) The amount of lateral displacement lost during the vertical movement, z, or during its corresponding horizontal movement x, equals yz, and

(c) The net amount of lateral displacement corresponding to x, equals 1 — yz.

4. The amount of movement down the slide-plane, corresponding to the horizontal movement x, equals $\frac{x}{\text{cos dip of slide-plane}}$.

The amount of lateral displacement corresponding to the sliding movement is the same as that which corresponds to x, as found under 3 (c).

5. The ratio of lateral displacement to motion down the slide-plane, when the total amount of the former is known, determines the total amount of the sliding.

By applying the foregoing to the data gathered at the Central mine, we find

1. In the triangle CC′E, if we make C′E=1 ft., C′CE=3° 18′, $\angle$ CC′E=90°. C′E : CC′ = sin 3° 18′ : 1, CC′ = $\frac{1}{\sin 3^\circ 18'}$ = 17.3432 ft. = x.

2. In the triangle FC′C″, $\angle$ FC″C′ = 5°27′ (the apparent hade* of the vein), and FC′C″ = 90°.

Then C′F = tan 5° 27′ = 0.095408 ft. = y.

3. (a) In the triangle CC′C″, $\angle$ C′CC″ = 20° 48′, CC′ = 17.3432 ft., C′C″ = tan 20° 48′ times 17.3432 = 6.588 ft.

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* The apparent hade is greater than the true hade by a very small quantity which for this demonstration may be neglected.

(b) $yz = 0.095408$ times $6.588 = 0\ 62855$ ft.

(c) $1 - yz = 1 - 0.62855 = 0.37145$ ft.

4. In the triangle $CC'C''$, $\angle CC'C'' = 20^\circ\ 48'$, $CC' = 17.3432$ ft., $CC'' = \dfrac{17.3432 \text{ ft.}}{\cos 20^\circ\ 48'} = 18.55 \text{ ft.} = z$. This motion down the slide-plane corresponds to a lateral displacement of the vein of 0.37145 feet.

5. $18.55 : 0.37145 = x : 285$ $\qquad x = 14,233$ feet.

It is thus possible, under the conditions stated, that the part of the Keweenaw series that lies above the Kearsarge conglomerate has moved from its original position, in a northerly direction, horizontally, about 2.7 miles, or along an inclined plane its equivalent distance of about 2.9 miles. These conditions are, first of all, that this movement took place down the steepest part of the conglomerate bed, and further, that the measurements of strike, dip, etc., of the conglomerate and of the vein—on which this result is based—are free from error. These measurements were made in part by Mr. Theodore Dengler, with instruments of precision, and in part by the Geological Survey, the latter being by pacing, but reasonably accurate.

In the foregoing computation the most conservative figures were taken, so that it is confidently believed that the result is not to any great extent exaggerated. If the dip angle of the conglomerate had been taken as 26° 56′, instead of 20° 48′, the possible amount of horizontal motion would have been nearly 35,000 feet, or if the hade of the vein had been taken as 7° 42′, which it actually is from the 9th level down, this amount would have been over 44,000 feet. Without attaching any great importance to these figures as indexes of the actual or even approximate amount of sliding that has taken place along the plane of the Kearsarge conglomerate, the demonstration is important as establishing, as above stated, a phenomenon thought to have been frequent on Keweenaw Point, and one that may have been to some extent a factor in the shaping of its topography, and intimately connected with its copper deposits.

§ 9. Conditions necessary to sliding of beds.

It needs no argument to show that for the explanation of a sliding movement such as that above described between beds of the same series, no recourse need be had to complicated causes. Planes of weakness in or between beds of the formation and a tilted position of the beds, whether from original deposition, or from a force acting at one point which depresses them (sedimentation), or from a force acting at another point which lifts them (intrusion), or from a folding which lifts or which depresses different parts unequally, are all that are necessary. If the dip be steep enough, gravity or the principle known as isostasy will tend to restore equilibrium, and the higher parts of a series will shear or slide over the lower parts or one series will shear over a lower one. The tops of sandstone and of conglomerate beds, from their evenness, afford planes of greatest weakness for the accomplishment of this movement.

Whether the fluccan of a conglomerate bed is in every case to be regarded, in whole or in part, as a product of some such sliding or shearing movement, or altogether as a layer of mud which covered the conglomerate at the time the overlying lava bed flowed over it, can not well be determined, but the sudden transition from coarse, solid conglomerate to fluccan should seem to indicate a different origin for the latter than as a mere stage in the conditions of deposition under which the conglomerate was laid down. Besides, we have the analogy of cross-fissures in which the presence of fluccan in connection with slickensides is clearly referrible to a sliding, or rubbing together of the two walls.

Having shown one sliding movement to have occurred in the Keweenaw series in connection with more or less finely ground rock material, we may naturally and logically infer that similar movements have taken place along other conglomerate planes where we now find fluccans. Indeed, the several conditions above set forth, as preliminary to slide-faulting, are such as to carry with them the conviction, without need of demonstration, that where these conditions exist in so marked a degree as on Keweenaw Point, extensive shearing must have taken place.

§ 10. Occurrence of fluccan.

A. Within the Keweenaw series. In the various cross-sections and literature of the Keweenaw series that have heretofore been published, there are found frequent references to beds of "chlorite," fluccan, clay, and to "slips," nearly all of which, like the fluccan in the Kearsarge conglomerate, are conformable with the ordinary beds of the series. Thus the Allouez conglomerate, as already noted,[*] is represented at Eagle River by a red clay seam six inches thick, called in early reports "the slide." This bed about two miles southwest of Eagle River gap, between the Cliff and Albion locations, is characterized by Foster and Whitney as a "thin belt of slaty chlorite about twelve feet in thickness."[†] At the Allouez mine this conglomerate shows about 6 inches of fluccan (clay) on the hanging wall, and in places itself attains a maximum thickness of 30 feet. About 16 feet from the foot wall there is a "sandstone slip."[‡] At Calumet this bed varies from 6 inches to 8 feet in thickness and is designated in a cross-section[§] by the officials of the Calumet and Hecla mine simply as a conglomerate, no mention being made of any fluccan. At the Peninsula (Albany and Boston) mine, latterly called the "Franklin Junior," about 4½ miles southwesterly from Calumet, the hanging of the Allouez conglomerate is described as fluccan 5½ feet thick. In the new adit southeast of the Quincy mine, about 4½ miles southwest of the Franklin Junior mine, the same bed is represented by a well marked seam of clay, within 50 feet of which and parallel to it, there are several "slips" in the contiguous beds.

The Houghton conglomerate does not appear at Calumet. At the Franklin Junior mine it has 3 inches of fluccan and at the Quincy mine adit a seam of clay, 1½ feet thick, on its hanging wall. In the Franklin Junior mine also, the Calumet and Kearsarge conglomerates are capped by fluccans respectively 4 and 16 inches thick.

Above the Greenstone at Eagle River a "slide" is noted by Marvine on the hanging of the first sandstone above the Ashbed and a similar slide occurs at about the same horizon in the Copper Falls mine.[||] The Kearsarge conglomerate at the Ahmeek location, as already stated, has 2 feet of fluccan on its hanging wall. None is recorded on the same bed at Calumet. Capt. J. C. Hodgson reports two feet of fluccan on the *footwall* of the Wolverine sandstone. In Sec. 25, T. 56, R. 33, according to the same authority, there is a

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[*] Geol. Sur. Mich.. I, Pt. II. p. 115.

[†] F. and W., Pt. II. p. 127.

[‡] According to Mr. Fred Smith. the Agent.

[§] Geol. Sur. Mich., V. Pt. I. Plate.

Capt. J. Vivian says this runs into the Ashbed at the Phoenix. so that it is not strictly parallel to the formation.

4-foot belt of fluccan interbedded in the Keweenaw series (Fig. 9).

B. Along the contact with the Eastern sandstone. Beside the above occurrences, within the Keweenaw series, similar material has been noted by many observers at different points along the junction between this series and the Eastern sandstone. Foster and Whitney early called attention to the belt of "fissile chlorite rocks"* which continues from Mt. Bohemia "almost uninterruptedly to Portage Lake and always preserving the same relation to the trap and sandstone," that is, between them. Irving and Chamberlin have described in detail an occurrance of this kind at Bête Grise Bay.† Wadsworth mentions a fault breccia 2 feet thick in Sec. 6, T. 54, R. 33.‡ In the same section at another exposure (further south) this breccia band is at least 9 feet thick. Not at all points of contact between the two series is the amount of breccia or fluccan equal, and there are even some points, particularly near the end of Keweenaw Point, where no fault breccia is noticeable between the sandstone and traps. The dips noted at these various points are in general steep, and there is no reason to doubt that the same sliding movements noted within the Keweenaw series, have taken place also at its edge, along the contact with the Eastern sandstone, at some points greater, at others less, and at others again, perhaps not at all.

§ 11. Topography as affected by slide-faulting.

The Kearsarge slide-fault, which was not confined within the limits of the east and west veins at the Central mine, but extended beyond them, to the east and to the west respectively, no one knows how far, and possibly other similar slides higher or lower in the formation may have left their impress on the topography of Keweenaw Point. The Central mine lies under the southern face of the Greenstone bluff, which from near the east line of T. 58, R. 28, forms the northern escarpment of the valley of Little Montreal River, and of Eagle River further west, thence curving southwards to the headwaters of the Trap Rock River near the Allouez gap. These two valleys of the Little Montreal and Eagle rivers form a depression between the Bohemian Range and the Greenstone Range that is 250 to 350 feet below the summit of the latter, and even more than that below the summit of the former. This depression is to a great extent covered by glacial drift, and is itself the result of preglacial erosion, and possibly, in some measure, of the sliding that took place along different horizons. From figures already given we can show that the plane of the Kearsarge conglomerate, if extended upwards from the edge of the bed as exposed in the Central mine, with a dip of 27°, which is about that observed on the highest part of the bed, would make the horizontal distance between the Allouez conglomerate at the base of the Greenstone and the extension of the Kearsarge plane opposite the Central mine, 5775 feet, or upwards of a mile. This would bring the plane of the Kearsarge conglomerate to the surface there, if the latter has the altitude of the Allouez conglomerate at the Central mine, at a point somewhere near the southeast corner of Sec. 26, T. 58, R. 31.

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* *Loc. cit.*, pp. 65, 66.

† Bull. U. S. G. S., No. 23, page 20.

‡ Report of the State Board of Geol. Sur., Mich., 1893, p. 163.

If the Greenstone ridge has actually moved respectively northward and westward by an amount equivalent to 2.7 miles horizontally, its southern face must previously have been nearly as far south as the center of Sec. 1, T. 67, R. 31, or immediately above the summit of the Bohemian Range. This would bring the south and east face of the Greenstone Range nearly if not quite into coincidence with the southeast slope of the Bohemian Range, the two forming one continuous mountain slope. In suggesting a theoretically possible former continuity of the eastern faces of these two ranges, I wish simply to point to the probability that, even if no such continuity existed, there may at least have been a large amount of movement of the upper part of the series away from the present line of contact with the Eastern sandstone, and that the greater the amount of this movement, the deeper and wider would be the resulting valley between the two ranges and the less would be the amount of succeeding erosion required both to carve out the valley and to reduce the crest of the sliding portion to its present level. The dip of the Kearsarge fault, where we now find the latter, is comparatively flat. With an increase of the angle of dip of the fault plane a correspondingly less amount of sliding would be necessary to reduce the altitude of the surface to a similar level, so that corresponding faults nearer the contact with the Eastern sandstone, where the dips are in general steeper, and where we should therefore naturally expect slide-faulting to be of more frequent occurrence, would, other conditions being favorable, tend to lower the general altitude of the series in a much more marked degree.

On the other hand, if the shearing in evidence along the Kearsarge conglomerate and other beds be only an incident in the process of folding to which the Keweenaw series has been subjected, we may have to attribute the valley of Eagle River and the Little Montreal largely if not entirely to the corrasive force of the ancestors of those streams, which, sinking along the slope of the formation, have attacked the softer beds under the Greenstone and gradually undercut the latter and carried away its debris. We may then derive from this alternative some idea of the magnitude of the erosive agencies that have been at work since the emergence of Keweenaw Point took place. The two forces, erosion and slide-faulting, thus seem to have worked to a common end, the one as a complement of the other. The greater the one, the less necessity was there for the other. Together they have reduced the level of Keweenaw Point to its present altitude. Slide-faulting along the planes of the Kearsarge and Allouez conglomerates, in the Eagle and Little Montreal River areas, would carry the higher beds north and west down towards the lake, in decreasing curves, which would have the effect of extending the shore line somewhat northwest and exposing in those areas flatter dips than if such faulting had not occurred. Whether this may be the explanation of the curve of Keweenaw Point and the contrast in dips between its northern area and the Portage Lake area, or whether these phenomena are due to other causes, cannot be determined more definitely as yet.*

§ 12. Structure of the Lake Superior basin.

We have thus far confined ourselves to the Keweenaw series as seen practically from one side of the basin only, and have laid down some broad principles, and have stated some facts not heretofore generally known. Let us extend our observations for a moment over the entire series. We know, as already stated, that dikes of eruptive rocks occur on the North Shore as well as on the South Shore. We may, therefore, suppose that some of the Keweenawan lava sheets originated on the North Shore. In the earlier part of this volume

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* See page 62

Dr. Lane has shown that the succession of rocks appears to be closely similar on each side of the lake, but that the thickness of the series on the North Shore is only two-thirds of its thickness on the South Shore. Unless we suppose that for almost every lava flow from the South Shore, an outflow of similar character occurred contemporaneously on the opposite shore—which is not likely—we must conclude that at least the basic flows came principally but not necessarily altogether from the same shore; that those beds that reached the bottom of the basin may have spread out to its opposite side, and encroached upon the shore line there from time to time. If the slope on the opposite side were gentler than on the side from which the majority of flows came, the beds at the former point would spread out thinner than at the latter point—a section through them would be shorter.

Now, unless we conceive it probable that a conglomerate bed, as such, can form *continuously* across a deep basin 30 or 40 miles wide, we must assume that the conglomerates of the Keweenaw series are merely marginal facies of deposition in the Lake Superior basin, i. e., that their rims were built up either on earlier lava beds or on the underlying Archean higher up the basin sides. The latter, therefore, as the name indeed implies, must have sloped towards the basin center and the lavas that formed a part of them must also originally have had a gradient, as has already been assumed. That conglomerates were thus laid down on lava beds is additional evidence that many of the latter must have flowed into or under water. If we assume that originally the steeper gradient was on the south side of the basin, and the gentler gradient on the north side, lava flows from one side or the other, if thick enough, could cover the basin floor and encroach more widely on the north or flatter shore, becoming thinner towards their margin. We should then probably find steeper original dips on the South Shore for beds extravasated there* and a thicker aggregate of beds than on the North Shore. To-day we find the beds of the Keweenaw series dipping from each side of the lake towards its center, the lower, or earlier beds more steeply at their highest points than the later beds. Along the southern edge of the series, we find acid rocks, distinctly intrusive, that may have contributed to these steeper dips and some others that may be a part of the underlying Archean. Near the northern margin of the series, on Pigeon Point, we find similar acid rocks of undoubted intrusive nature, and on Isle Royale acid rocks of probably similar origin.* Further back, on each side of the lake we find the Archean. Thus in their main features the two sides of the basin appear to be similar in the character of their rocks and in their structure. The flat dips of the North Shore lavas to the south may be due to intrusions and to folding.

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*The steeper dips above the Greenstone at Eagle River may be due to this cause, or these beds may originally have had a steeper gradient than the underlying Greenstone because of their greater acidity and consequently greater viscidity. See Chapter III.

I have now stated the principal observations (anticipating several) on which I have endeavored, in passing, to erect the frame of a working hypothesis. These observations have been given in great part in the order in which they were made. The systematic arrangement of field observations covering so large an area, and suggesting so many deductions, must always be a matter of great difficulty, and I cannot claim to have succeeded in this particular to the extent that the subject demands. Parts of this hypothesis are offered with some diffidence, because they are opposed to the views of some very eminent and very experienced investigators of Lake Superior geology, and, on the other hand, with some confidence, because I believe them to involve fewer assumptions, and to be the more natural deduction from certain observed phenomena, than some views heretofore advanced. Owing to the fact that the examination of the copper district in Michigan is not yet completed—much less that of the other parts of the series in neighboring states—it would be very venturesome to state in precise terms any theory as to the life history of the Keweenaw series, or to claim infallibility for it, when stated. I have, therefore, in submitting the facts observed by the Survey, drawn certain inferences, which I wish to be considered largely as tentative. If they should bear the test of time we may finally, when all the facts are in, arrive at a satisfactory explanation of many questions that have thus far been difficult of solution. In the following pages I shall have occasion to enter somewhat further into a discussion of the same subject and shall reserve until later a résumé of the conclusions to which my investigations thus far have led me.

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*Bayley. The Eruptive and Sedimentary Rocks on Pigeon Point, Minnesota, and their Contact Phenomena. Bull. U. S. G. S., No. 109, 1893.

CHAPTER V.

ACID ROCKS OF THE PORTAGE LAKE AREA.

§ 1. Wall Ravine to Douglass Houghton Falls.

In Wall Ravine, Sec. 20, T. 56, R. 32, near the hanging of the St. Louis conglomerate, we find a few ill exposed outcrops of a felsitic rock carrying large numbers of small spherulites. The exact relations of this rock to the conglomerate cannot satisfactorily be made out; there are no positive indications that it is intrusive. Its presence here, at one point near the hanging of the conglomerate and at another near its footwall, may, however, be taken as a point of resemblance of this horizon to that of the Bohemia conglomerate at the Little Montreal River, where we found conglomerate beds and acid flows in alternation, and above which no original felsites have thus far been noted. This bed is thus an additional indication of the probable identity of the two conglomerates, the Bohemia and the St. Louis. Apparently below this horizon (Fig. 9) there is a bed of "jasper," exposed in the face of the water-fall in the next section southwest (Sec. 30), which is probably the northward continuation of the quartz porphyry noticed by Merriam below Douglass Houghton Falls,* in Sec. 36, next southwest.† It is a fine grained dark red rock, resembling much the felsites of the Bare Hill area, but carrying more free quartz (S. 12887), and is underlain by a fine grained porphyrite. At the point of exposure it dips westerly about 33°. No outcrop that closely resembles this bed has been seen except the one at Douglass Houghton Falls, but in Sec. 36, T. 56, R. 33, a short distance southwest of the latter falls, in the ditch on the west side of the Torch Lake and Calumet R. R., there is a small outcrop of coarse quartz porphyry, described by Irving.* It is a similar rock, as Irving pointed out, to the pebbles that characterize the Allouez conglomerate at the Albany and Boston (Peninsula, Franklin Junior) mine in Sec. 8, T. 55, R. 33, as well as the Calumet conglomerate at Calumet. No outcrop of original acid rocks has been found between here and Portage Lake unless a thin bed of "jasper" be such, that is marked as No. 6 (7?) of Marvine's conglomerates.†

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*Bull. U. S. G. S., No. 23, p. 43.

†There is an apparent discrepancy between the location of this porphyry by the Survey and that of Capt Hodgson's map. According to the former the falls in Sec. 30 are further west, and the porphyry between the falls and the point where exposed in a trench further south, strikes more southerly than in Fig. 9. In either case, however, the horizon of the conglomerate in Sec. 30 appears to be above that of the porphyry.

On a previous page (32) reference was made to the theory of Von Richthofen. We have seen that the felsites interbedded with the Bohemia conglomerate mark the culmination of acid eruptions and flow on Keweenaw Point in this part of the Keweenaw series. We have traced this horizon, not everywhere equally acid, and marked by rocks that vary from fine grained to coarse, down to the vicinity of Torch Lake. Above this horizon lies the vast mass of the known Keweenawan, but nowhere in the latter, in this area, do we find original rocks of equally high acidity. The intrusive felsites of Fish Cove, of West Pond and of Bare Hill, being later than those of the Bohemia belt, can therefore not be connected with any known similar rock elsewhere that is interbedded with the melaphyres and conglomerates (i. e. extrusive). Whether they reached the surface other than by denudation we do not know. They are important only as marking a second period during which very acid magmas were active within the crust of the earth, or better, perhaps, the end of the period of activity of very acid magmas that began back in the Huronian.

We know, however, of several horizons in the series on Keweenaw Point that are marked by rocks of medium acidity. The porphyrite on the east side of Fish Cove Knob is one of these. Another is the porphyrite above the Lac la Belle conglomerate at Bare Hill and in Sec. 30, west of the latter, probably also under bed A, Sec. 26, T. 58, R. 28 (Pl. II). Above the Bohemia belt we find next below the Kearsarge conglomerate another rock of medium acidity, followed, higher in the series, by the porphyrites of the Ashbed group. Thus there are already known on Keweenaw Point at least five, more or less well-marked horizons of medium acid to very acid rocks. It will be of interest to see whether these horizons are persistent further south, throughout the series, and whether each one is similarly acid elsewhere.

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* Copper-Bearing Rocks of L. S., p. 196.

† Geol. Sur. Mich., I, Atlas, Pl. XIV b.

§ 2. St. Louis conglomerate south of Wall Ravine.

The St. Louis conglomerate has its greatest observed thickness at Wall Ravine, in Sec. 20, T. 56, R. 32, where it is exposed for about 70 paces along the sides and bed of the ravine. At this point it is in contact with the Eastern sandstone, and near the line of junction it is so much shattered and altered as to be, in places, almost unrecognizable as a conglomerate. From here southwesterly it is seen at frequent intervals in natural exposures and in mine pits and adits as far as the St. Louis ravine near the south line of Sec. 19. Here, at the old stamp mill it is only 6½ feet thick, dips 47° N. W. and strikes N. 36° E.*

The next indications of a detrital bed southwest of Sec. 30 in this general horizon are at Douglass Houghton Falls, where, about 40 feet above the bottom of the ravine, in the face of the wall over which the stream is precipitated, there is a 4-inch seam of sandstone that appears thus far to have escaped the notice of the many geologists that have examined this historic spot. It dips northwest about 22°-23°, and apparently strikes N. 20° E., or even more to the east. It is medium fine grained, with a dark red basic matrix. This seam lies between beds that are very much brecciated, the lower one being apparently the thicker and the more brecciated. They are very chloritic and red, and one cannot say positively what the rock was originally, whether conglomerate or trap. There are so many slips in the formation here that the position of the sandstone with reference to the quartz porphyry could not be positively determined, but the latter seems to be below the former.. This brecciated zone with its sandstone may possibly be the horizon of the St. Louis conglomerate, which, as we have seen, was thinning out rapidly towards the southwest and lay above the porphyry. The foot of Douglass Houghton Falls is about 130 paces from the contact with the Eastern sandstone down stream. We have already noted just south of Wall Ravine the occurrence of trap for about 200 paces below the conglomerate. The joint planes of the trap beds at the top of the falls, dip northwesterly about 24°. From this point, which is 368 feet above the level of Torch Lake,† only basic rocks are exposed in the stream bed, westerly, as far as the Calumet road.

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* Bull. U. S. G. S., No. 23, p. 28. According to Foster & Whitney, the dip here is 42°.
† *Ibid.*, p. 49.

§ 3. Conglomerates southwest of Douglass Houghton Falls.

From the Allouez gap to Sec. 30, T. 56, R. 32, the section northeast of Douglass Houghton Falls, the course of the St. Louis conglomerate has been very close to that of the contact between the Keweenaw series and the Eastern sandstone. That course, if continued southwest, would carry the conglomerate near the horizon of the Torch Lake quartz porphyry, but as indicated above, the conglomerate has probably wedged out before reaching the porphyry. The latter outcrop is only a few feet in diameter, but whether it is, (1) intrusive, (2) interbedded, or, (3) belongs to the underlying Archean, we have as yet no means of knowing. If intrusive, the porphyry is probably older than the Kearsarge conglomerate, because the latter and subsequent beds contain many pebbles that resemble this porphyry; probably younger than the St. Louis conglomerate and the contact conglomerate further south, for these do not seem to contain a similar rock. Moreover, it is quite apparent from the regularity of the strike of the beds higher in the series opposite this point, that the intrusion, if there was one, was either quite early in the history of the series, or else its effects were either not violent or not far reaching.

The next conglomerate outcrop southwest near the Eastern sandstone contact is found in Sec. 11, T. 55, R. 33, at 1400 paces N., 400 paces W., of the southeast corner, or about 1 2-3 miles from the Torch Lake porphyry. (See Pl. VIII.) It is well exposed here on each side of a stream for about 8 paces in width, dips westerly 36°-38° and strikes N. 15° W. The position and strike of this bed are in harmony with the suggestion (1) that it curves around the Torch Lake porphyry, that is, that it was lifted and flexed by the latter. If it shall be found not to contain pebbles of this porphyry—the Survey has noted none—the above suggestion will have the force of strong probability. On the other hand, should fragments of this porphyry be found in these conglomerate beds the porphyry may be (2) interbedded, or (3) it may belong to the Archean.

We appear to have entered here an area that differs from that immediately adjacent to the St. Louis conglomerate north of the Torch Lake porphyry. The overlying melaphyres seem to be less crystalline and more amygdaloidal than the beds at the more northerly point, and the conglomerate itself, as we shall see, follows a very irregular course. That we may be in a different horizon and that the conglomerate here may not be a continuation of the St. Louis bed is quite possible. For this reason I shall provisionally, at least, call the former the "contact" conglomerate.

About half a mile almost due south of the above outcrop the conglomerate next appears at the upper falls on Hungarian River, almost in contact with the sandstone, only a bed of trap separating them. It dips westerly about 33° and strikes about N. 12° E. For nearly half a mile above the falls the melaphyres and amygdaloids are much shattered. No other conglomerate was observed there.

From this point southwest the same conglomerate is found exposed in the beds of small streams, and probably at about 800 paces N., 1875 paces W., of the southeast corner of Sec. 14, T. 55, R. 33. In Sec. 22, about 750 paces W., near the north line of the section occur outcrops of sandstone and of a conglomerate with a very sandy matrix. The pebbles in the conglomerate are subangular and some of them are of quartz porphyry. The dip is about 50°-54° N. W., strike about N. 45°-50° E. The stream is full of slabs of these rocks and one or two hundred paces up the stream there are several large blocks of red sandstone on the east bank. I believe that this conglomerate is a part of the Eastern sandstone series.

Further west, along the north line of Sec. 22, near the north quarter-post, a larger stream shows exposures of a conglomerate that carries many rounded pebbles, principally of acid material, with a small amount of quite coarse matrix. No bedding is noticeable and the rock looks much like a recent deposit except that the pebbles are more abundant and the cementing material harder, than usual. This may be a part of the bed we have traced from the northeast. About 75 paces west of the north quarter-post of Sec. 22, just south of the line, and also higher up the stream in Sec. 15, there are several outcrops of rock with very abundant amygdules, largely of calcite, and to a less degree of an amorphous white substance. The dip of these beds is apparently very flat, as low as 15° or less.

The junction of the Keweenaw series and Eastern sandstone is next seen about a mile further west (1750 paces N., 850 paces W.)

in Sec. 21, T. 55, R. 33, on the banks of a small stream that flows south. A conglomerate here, underlain by trap, strikes N. 72° E., and dips northerly 44°, the trap being in contact on the south with the sandstone, which is much broken and disturbed but appears to dip rather flat to the N. E. The sandstone here is 414 feet above the level of Portage Lake. From this point the sandstone contact can be traced southwest, past the west quarter-post of Section 21 (Alt. 416 feet above Portage Lake), through Sec. 20, into Sec. 29, thus making a sweeping curve to the south (Pl. VIII). At several points along this contact in Sec. 20 a conglomerate outcrops and is in places underlain by trap, compact or amygdaloidal, and appears to run very nearly parallel with the contact line, but whether it is the same bed in all cases can not be positively affirmed. Further south in Sec. 29, in very nearly the same horizon, occur three outcrops of conglomerate, two of which may possibly belong to one and the same bed. No satisfactory correlation has thus far been made between any of these and the bed in Sec. 21. The strike of these beds, however, corresponds more nearly though not exactly with that of beds higher in the series, and is thus in contrast with the strike of the former—N. 72° E. Whether the latter bed be the continuation of the "contact" conglomerate followed from Sec. 11 north of Hungarian Falls through Secs. 14 and 22 is a matter of inference.

If we follow the courses of several conglomerates where they can be traced connectedly, we see that from Wall Ravine the St. Louis conglomerate appears to have run southwest with the usual strike of the overlying beds and probably to have wedged out somewhere north of the Torch Lake quartz porphyry; that a conglomerate close to the contact of the traps and Eastern sandstone first again comes to view in Sec. 11, 1 5-8 miles south of the porphyry. Here, however, the conglomerate strikes S. 15° E., and must soon curve westward as it goes south, for at the next exposure at Hungarian Falls, it strikes S. 12° W. and continues from this point through Sec. 14 with a strike about S. 40° W. If the conglomerate seen on the north line of Sec. 22 is a continuation of this bed, the latter is certainly swinging enough more to the west to merge with the conglomerate in Sec. 21 (1750 paces N., and 850 paces W.), and must there have a strike nearly east and west. That it should swing back from this point, into line with some of the conglomerate outcrops of Secs. 20 and 29 is no more improbable than that it here runs east and west. Whether or not we accept the latter correlation of this contact conglomerate, we are at least positive of its course in Sec. 11 (S. 15° E.), and see that this is quite out of conformity with the higher beds of the series. This is not the only case of the kind that we shall meet in this part of the series and in this area. We may account for it by supposing that a wide section of the trap series between Sec. 21, T. 55, R. 33, and the head of Torch Lake has been faulted east and let down against the Eastern sandstone. The presence of a small north and south fault in Sec. 21, and other evidences of disturbance in the traps, the flexure of the Eastern sandstone at the contact, and the fact that it *apparently* underlies the traps, the flatter dips and irregular course of the contact conglomerate, all lend color to this suggestion, and that some such movement has in fact taken place in this area is not at all improbable, but that it was on such a scale as to account for the apparent flexure in the contact conglomerate —its deflection from parallelism with overlying beds—is improbable. Besides, the different character of the beds immediately above the conglomerate—more amygdaloidal than those above the St. Louis conglomerate opposite Wall Ravine—should seem to indicate, as previously remarked, a difference of horizon for the two conglomerates, or, if these are in fact coeval, it may indicate either that the more southerly portion was deposited along the margin of an embayment (See Fig. 7), or was flexed by some orogenic movement early in the history of the series. Whether the two conglomerates represent the same or different horizons is, so far as the present discussion is concerned, of little moment. The curve of the contact conglomerate represents a trough that was filled by a series of rather thin lava flows, before the period of the more massive flows began that we find above Marvine's conglomerate bed No. 3. (Geol. Sur. Mich., I, Atlas, Pl. XIVa). The question arises: Can not this trough have been in the rim of an early Keweenawan or pre-Keweenawan basin, and are not the low dips of the early beds and the high dips of the later beds and the irregular course of the contact conglomerate thus best accounted for? If this area had been near the center of a basin, would not the lava beds that flowed into it, and the conglomerates that lined it, be more nearly conformable? If early intrusions be answerable for the flexure of the conglomerate, such intrusions, lifting the strata, would thereby form raised margins to the surrounding depressions, and the resulting structure would be the same. The locus of the intrusions would thus become the rim of a basin.

§ 4. Conglomerates south of Portage Lake.

In Sec. 31, T. 55, R. 33 and in Sec. 6, T. 54, R. 33, next south of the former on the south side of Portage Lake, two conglomerate beds have been traced, one of which seems to be the continuation of the bed we have been following. They are Nos. 1, 2, and 3 of Marvine.[*] His beds Nos. 1 and 2 are thought to be one and the same bed, which appears to run nearly north and south through Sec. 6, and outcrops on the north line of that section, 500 paces E. of the N. W. corner.

The divergence of the two conglomerate beds is seen on the map (Pl. VIII), and the curvature of No. 1 marks this bed as being possibly the southward extension of the so called contact conglomerate, which we have traced on the opposite side of the lake. It at least calls to mind the sinuous course of that bed. A heavy covering of drift conceals the respective positions of these beds nearer Portage Lake. Between these two conglomerates, that is, No. 1 and No. 3, occur a succession of scoriaceous beds uncovered in a line of trenches in Sec. 6, T. 54, R. 33, dug by Mr. Mabbs[†] across the property of the Isle Royale Mining Company, as far east as the sandstone contact. No conglomerate was found in these trenches below No. 3 until the contact conglomerate was reached—an additional piece of evidence—so far as it goes—for considering Marvine's conglomerate No. 2 as the northward extension of No. 1. The space between conglomerate No. 3 and the contact conglomerate is thus seen to be bowl-shaped like the embayment in Secs. 11, 14 and 15 on the opposite side of the lake (Pl. VIII) and to be filled, like the latter, with rocks that differ radically from the coarsely crystalline rocks immediately above conglomerate No. 3, and similarly, from those above the St. Louis conglomerate at points north of the Torch Lake porphyry. Conglomerate bed No. 3, then, seems to mark for the south side of Portage Lake the bottom of that part of the series whose beds show a widespread conformity of dip and strike, as well as a more massive and crystalline character. It thus marks an era when this part of the Keweenawan area was being leveled up by the filling of pre-existing channels in the rim of the basin. That area was gradually thickening and expanding eastward, up the side of the basin, only to suffer periods of degradation and contraction during which material from the higher parts of the basin rim was transported to and accumulated in the conglomerate beds nearer the basin center. Let us see if we can find the equivalent of conglomerate No. 3 on the north side of Portage Lake.

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[*] Geol. Sur. Mich., I, Atlas, Pl XIVa.

[†] Geol. Sur. Mich., I, Pt II, p. 62.

§ 5. Correlation of some Portage Lake conglomerates.

On a previous page I have indicated the probability that Marvine's conglomerate bed No. 2 is identical with bed No. 1—the contact conglomerate. Marvine and Emerson located* between the contact and the Isle Royale cupriferous bed six other conglomerate beds, which, in order to avoid confusion we shall continue to designate by their numbers, 3 to 8. Bed No. 8 (scaled from Marvine and Emerson's plat, not allowing for a small difference of elevation which will slightly reduce the horizontal distance) lies 670 feet horizontally† east of the Isle Royale bed. This bed and No. 6 are characteristic pebble conglomerates. Number 7, 510 feet east of No. 8 and 350 feet west‡ of No. 6, is a very characteristic seam of fine grained indurated sandstone, called by mining men "jasper," and at one or two points appears to be closely associated with a conglomerate of porphyritic material. The position and course of these three beds have been satisfactorily determined by the Survey as far south of Houghton as Five Mile Hill in Sec. 16, T. 54, R. 34. The course of the Isle Royale cupriferous bed, as laid down by Marvine and Emerson for a mile back of Houghton, appears to be closely in conformity with that of the above conglomerates, while the course of the Grand Portage bed west of the former appears according to the same authorities to approach the Isle Royale as it comes north.§

On the north side of Portage Lake a cupriferous bed, supposed to be the continuation of the Isle Royale was opened in the Douglass, Concord and Arcadian mines, in Secs 30, 19 and 20, respectively, in T. 55, R. 33. *Six hundred and sixty* feet horizontally east of this bed, a conglomerate closely parallel with it, has been traced for nearly a mile and a half. Marvine and Emerson correlate this bed with No. 7, with whose predominant characteristic, "jasper," it does not however agree, and locate 360 feet (scaled) east of it bed No. 6, which they designate "jasper" and which thus appears to correspond in character although not, by 150 feet, in position to No. 7 on the south side of the lake.* Marvine says "the bed on which the Concord and Douglass mines are situated is some distance east of either the Isle Royale or Grand Portage beds,"† but gives no reason for his opinion. If this opinion be well founded, conglomerate No. 8, unless cut out, should occur within 160 feet east of the Douglass-Arcadian cupriferous bed (for the distance between No. 7 and No. 8 on the south side of Portage Lake is 503 feet), but no such bed has ever been seen.

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* Geol. Sur. Mich., I, Atlas, Pl. XIVa.

† Mr. R. C. Pryor by actual measurement, allowing for difference of elevation, makes the horizontal distance 650 feet.

‡ Measured by the Survey on the Isle Royale location.

§ The relations of these two beds to each other must be left to a future report.

The above evidence is entitled to great weight in deciding as to the correctness of Marvine's correlation. If the latter is wrong and if as above suggested, the conglomerate next east of the Douglass-Arcadian bed is in fact No. 8, then the Douglass-Arcadian bed must be the extension either of the Isle Royale or of the Grand Portage bed, or possibly of the union of these two.

Lying not more than 350 paces (not over 1000 feet horizontally) east of the above conglomerate in Sec. 20, T. 55, R. 33, is another well marked conglomerate which follows a course parallel with that of the above beds into the north half of the same section. This may be bed No. 5, for it corresponds closely to the position of No. 5 on the opposite side of the lake. No other conglomerates have been noted in this area until we reach the eastern part of the northwest quarter of Sec. 29 in the same township. The course of the latter beds is at an angle to that of the others above noted, so that somewhere between their horizon and that of No. 5 must be the horizon that corresponds to conglomerate No. 3 and to the sub-crystalline traps on the south side of Portage Lake. The last named conglomerate may, then, be the extension of the St. Louis or Bohemia conglomerate.

§ 6. Portage Lake as a fault line.

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* This "jasper" bed I have never been able to find on the north side of the lake.

† *Ibid.*, p. 58.

Marvine thought that Portage Lake represents an old fault line and that the north side has been heaved about 720 feet to the west,[*] his determination having evidently been made from observations on the Albany and Boston (Allouez) conglomerate, higher in the series. The correlation from one side of the lake to the other, and the possible location of deposits on one side known to exist on the other, made it desirable to do some work to determine whether this dislocation, if it really exists, affects as well the lower beds of the series, and if so, to what extent. This work was confided to Mr. W. W. Stockly, who established his stations by triangulation by means of the transit, with reference to the north quarter-post of Sec. 30, T. 55, R. 33, and also to the S. W. corner of Sec. 36, in Hurontown, in the section next southwest. The altitude of the different stations was determined with a wye level by Mr. Stockly on the north side, and by Mr. W. L. Cumings on the south side of the lake.

The outcrop of the conglomerate (No. 8) next east of the Douglass-Arcadian bed was followed and located for 4152 feet. The difference of elevation (106 ft.) between extreme stations, with a dip of 54° gave the true strike of the bed N. 36° E.,[†] which was platted to lake level. The line of apparent strike was then carried across the lake, and from it outcrops of conglomerate No. 8 were located, and their altitudes determined by leveling. These points, taking the same dip, were also platted to lake level and all the points joined, as in Plate VIII. The resulting line represents a true strike that varies, between points A and D, only 3° 20′. The distance between A and D is about 15,000 feet, and were the lines of strike at these points produced until they met in Portage Lake, the horizontal distance between them could not be greater than 275 feet. These figures then must represent the maximum of faulting possible at this horizon, in offsets distributed over a distance of about 15,000 feet. There is no evidence to show that the offsets all occur within the limits of Portage Lake itself, and for the distance across the lake, 1,500 feet, the apportionable amount would not be greater than 27.5 feet[‡]. From just what correlation the amount of Marvine's supposed fault in Portage Lake was derived, does not appear in his report, for the

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[*] Geol. Sur. Mich., I, Pt II, p. 61

[†] With a dip of 57°, the strike would be N. 36° 53 E. This dip is probably more nearly correct than the one above assumed (54°), but the difference in the curve would be very slight.

[‡] With a steeper dip, as above suggested, this amount would be still less.

Albany and Boston conglomerate on which most of his work was done does not seem to have been recognized by him on the south side of the lake. That so marked an increase in the amount of dislocation should have taken place between the horizon of the latter bed and that of No. 8, within the limits of Portage Lake, while it may be possible, does not seem probable, unless the fault be one that cuts the series diagonally and is not disclosed in the areas thus far explored. Any more decided opinion on the subject, however, may well await the result of further investigation.

§ 7. EASTERN SANDSTONE.

A. End of Keweenaw Point. The Eastern sandstone outcrops at several places along the southern shore of Keweenaw Point, notably in Sec. 26, T. 58, R. 29, where Irving and Chamberlin examined and described it in detail (Pl. IV, points A and B[*]); about the middle of Sec. 30, T. 58, R. 28, (point B2) where it is exposed for about 100 paces, and was noted by the United States Linear Survey; east of the center of Sec. 29, T. 58, R. 28 (point C)[†] where it is exposed for some 300 paces; and on Sec. 35, T. 58, R. 28 (point D), where it covers the bed of the lake for several hundred paces, and runs up to the low shore cliff but does not appear above the water. In each of these places it has similar characteristics, being rather coarse grained, quartzose, whitish and somewhat feldspathic. On Sec. 26, T. 58, R. 29, it is associated with beds of basic and acid rock-fragments of small size, generally angular, in a red shaly matrix. At the other points, further east, beds of exactly similar character to these last do not appear to occur in connection with the sandstone. The latter is arranged in folds dipping lakeward, and erosion of their upper edges has produced the effect of making it appear to approach and recede from the shore in distinct curves which from high points on the shore may be seen to extend far out under the waters of the lake. The dip of these beds varies from 30° to vertical, and in fact, in one place (point B) the beds are supposed to be overturned, and dip to the north.[‡]

During the work of the Survey in 1895 and 1896, beside the occurrence of sandstone on the lake shore in Sec. 35, T. 58, R. 28, that of two others was noticed. One of these was in Sec. 27, T. 58, R. 28, at 1190 paces north, 280 paces west. In a small basin inclined slightly to the north on the right bank of the Little Montreal River, the ground for 20 paces north and south and 12 paces east and west, is strewn with slabs and thick fragments of the characteristic white, round grained and coarse grained sandstone, like that on Sec. 26, T. 58, R. 29. These slabs are very crumbly, a part of their constituents being largely decomposed kaolinite. The elevation here, above Lake Superior, is from 80 to 85 feet.

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[*] Bull. U. S. G. S., No. 23, 1885, p. 18.

[†] *Loc. cit.*, p. 23

[‡] *Loc. cit.*, p. 23.

The other occurrence of sandstone is in Sec. 26, T. 58, R. 28, about 760 to 780 paces north, 1420 paces west. Three or four pieces of the same coarse, whitish to reddish sandstone are exposed at the southern base of the hill at the southeast end of West Pond (Pl. II). One of these outcrops, more reddish than the others, somewhat finer grained and containing no kaolinitic matter, alone of all of them appears as if it might be in place. Excavation alone can settle this point. This outcrop is exposed for 6 or 8 feet east and west and is 3 feet or more thick, and seems to lie very nearly horizontally. The others are more or less discordant, smaller in extent and have evidently been disturbed. In one of them were noticed inclusions of quartz and of quartzite, and of fragments of what seemed to be quartz porphyry, now reduced to kaolinite. It is somewhat significant that this sandstone is near the 80-foot contour line, or at about the same horizon with the fragments in Sec. 27, previously described. This fact and the apparent total absence of other blocks or even fragments of similar sandstone in this entire burnt area lead one to believe that these sandstones are on or near the place of original deposition. All through these two sections as far as examined, and especially around the pond near the outcrops last mentioned, the soil seems to be largely, if not altogether, of whitish sand, the upper limits of which are between the 80-foot and 90-foot intervals. The very nearly *horizontal position* of the last named sandstone, near an intrusive felsite, as contrasted with the disturbed condition of the sandstone on the lake shore in other places, is an argument in favor of the conclusion that the disturbance in the latter areas is not due to the gentle and simultaneous tilting of the series, but rather to local movements, such, for example, as the lakeward slipping of the traps. The prevailing dip of the traps in Sec. 26, T. 58, R. 28 is 54°, nearly the maximum known for the corresponding horizon throughout the series, and yet that dip and the steeper dip of the beds affected by the intrusive felsite of West Pond had been assumed before the deposition of the sandstone—if, at least, we can rely on the outcrop in Sec. 26 as being in place.

B. Bare Hill. By far the most interesting occurrence of Eastern sandstone in this, or perhaps any other area, is that which lines the shore near the foot of Bare Hill, in Sec. 29, T. 58, R. 28. From a distance this outcrop might easily be mistaken for felsite. Indeed, Irving appears to have included it in his Bare Hill felsite belt,* although later, on Rominger's authority† he and Chamberlin corrected the error.

Irving and Chamberlin quote from manuscript notes of Dr. Rominger, 1884,‡ the following description of this outcrop:

> Further east another large patch of sandstone occurs on the shore near the center of section 29, township 58, range 28. In the outer portion of this patch the strata dip under an angle of about 20° south, but, following the exposures along the shore eastward, this inclination decreases, and finally, near the spot where the sandstones come in contiguity with the diabase, they are horizontal.

In his report as finally printed§ Rominger says of these sandstone beds that—

> They have a distinct southern dip, steepest off shore, and diminishing toward the shore, near their contact line with the diabase, where the strata have an almost completely horizontal position, which circumstance makes me suggest as the possible cause of the inclined position of the strata an underwashing of the beds in the lake-bottom and the subsequent breaking down of the more superficial strata. Their discordance with the diabasic rock belt is here just as plainly observable as in the former place; crevices in the diabase are often found replenished with sandrock.

The above observations are substantially in accord with those made by the writer. The outcrop in question extends along the shore from near the center of Sec. 29, between 300 and 400 paces eastward (Pl. IV). At its west end it overlies the trap—an ophite—and dips about 25° to the southeast, looking exactly as if it had slipped lakeward over the surface of the latter. At the east end no disturbance is apparent; the sandstone alone is exposed here in a solid mass.

Following the contact on the west, back from the shore up the slope for 75 paces, we pass large blocks of sandstone, some of them many tons in weight, disturbed and evidently out of place. Near the top of the shore ridge (100-180 feet above lake level) that evidently corresponds to the terrace back of the shore-felsite further west, we find just east of the trap, a vertical wall of sandstone about 50 feet high that extends 50 to 75 paces east. It has here the appearance of a compact original mass in place, and while no conclusive evidence of bedding was seen, the sandstone has all the appearances of horizontality. The contact of the sandstone with trap in the shore ridge on the east side of this hill is marked by a small spur of sandstone running lakeward and apparently somewhat harder than the same rock elsewhere at this place. This outcrop thus has an approximately semi-circular form, and lies in an embayment on and against a steep wall of trap where it has been protected from total erosion. Its position is such as to make the conclusion irresistible that it was laid down against the shore cliff unconformably on the trap series, after the tilting of the latter and probably after the intrusion of the Bare Hill felsite. This is the view early advanced by Agassiz, Pumpelly* and others, as to the relations of the Eastern sandstone and the Keweenaw series in general.

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* Copper-Bearing Rocks of L. S., Pl. XVII.
† Bull. U. S. G. S., No. 23, Plate II.
‡ *Loc. cit.*, page 17.
§ Geol. Sur. Mich., V, Pt. I, page 136.

Before adding any further observations on the relative ages of the sandstone and the trap series, it seems more properly in place to consider certain contact phenomena from which have been drawn some quite important conclusions as to the structure of the two series.

§ 8. Theory of a deep-seated fissure in the Keweenaw series.

The theory of Irving and Chamberlin, briefly stated, is that the Keweenaw series is essentially bedded, built up by lava flows extravasated near the margin of the Lake Superior basin, and by horizontally deposed conglomerates and sandstones alternating with the former; that the more basic flows, from their greater fluidity, spread out over a wider extent than the more acid and viscous extrusions, which tended to accumulate in "thick embossments" near the loci of eruption, where they were the more exposed to rapid degradation; that the accumulation of this material was accompanied by a slow and progressive subsidence of the beds near the center of the basin and their elevation in the districts of eruption, that is, the Marquette-Gogebic region and the northwestern shore of the lake in Minnesota and Canada; that thus the uplifted margins of the lava sheets were themselves supplying the material for the conglomerates and sandstones that were from time to time interbedded with them. Irving and Chamberlin believed that the dips of the Keweenaw series are uniform and steady, and that the junction line between that series and the overlying Eastern sandstone is gently undulating. They point with emphasis to the disturbed condition of the Eastern sandstone along the line of contact, and to the presence of a fault plane at many points on that line, and believe that these phenomena can best be explained by supposing the long contact line between traps and sandstone to be the result of "ancient faulting," that is, by faulting that took place before the Eastern sandstone was laid down, "modified by subsequent erosion and by still more recent slight faulting," but they entertain no very confident conclusions as to the precise nature of the earlier fault. In this contention they assume the existence, *within the Keweenaw series*, of a deep seated, hidden fault plane of whose existence they freely say they have no direct evidence. The cause of the faulting lies, they think, in the expanded condition of the earth's crust in the districts of volcanic activity (the Marquette-Gogebic region) during the long process of eruption—a progressive elevation—followed by contraction, which may have caused a differential subsidence between the Keweenaw Point area and the region south and east of it. The upward curving of the sandstone, noticed at many points, was caused, they conclude, by the depression of the sandstone or by an upward thrust of the Keweenaw series—a reverse fault.

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*Geol. Sur. Mich., I, Pt. II, page 4.

While both the upward curves and the downward curves of the sandstone at the immediate contact, together with the character of the overlying and underlying contacts themselves, may be the results of a reverse or thrust fault as just noted, Irving and Chamberlin point out that similar results might be produced by an individual movement of beds in the Keweenaw series on each other, during the last faulting. "That faulting may be distributed along several planes that offer comparatively small shearing resistance," they say, "is affirmed by theoretical considerations, experimentation and observations in nature. "We have," they say, "at times been inclined to believe that the post-Potsdam disturbance was due to a slight irregular movement of this kind, but the increased evidence now at command seems to strengthen the probability that there was a definite, and not inconsiderable, faulting movement somewhat of the kind above indicated."* To the foregoing Irving and Chamberlin add a number of arguments why the Eastern sandstone should be considered as having been laid down unconformably on and against the Keweenaw series, a conclusion which the recent work of the Michigan Survey seems to verify.

Irving and Chamberlin's views with reference to the fault along the junction of the two series do not, however, seem fully to satisfy certain observed phenomena described in the previous pages. The fault or fissure theory has had many advocates. Foster and Whitney thought there was no doubt of the existence of a deep seated fissure between the end of Keweenaw Point and the western limits of the district along the line of which was protruded the Bohemian Range.† Rominger thought the trap range had been subjected to a submarine upheaval, subsequent rupture, and that its western horizon finally emerged from the water.‡ Wadsworth§ thought that the first lava of the Keweenaw series "flowed over the Eastern sandstone, which is older than the copper-bearing or Keweenawan series. Subsequently a fault line or fissure was formed, running near what is now the point of contact of the sandstone and lavas, sometimes exactly at that point, sometimes on the lava side, and probably sometimes on the sandstone side of it. Along the fissure it is probable that a normal fault occurred * * * * *." The same general idea of a deep seated fissure penetrating the series itself, the Keweenaw series in the one case, and the Potsdam in the other, seems to have been held in common by the above investigators. Pumpelly and Brooks, among the geologists that have expressed an opinion on the subject, are the only ones to reject the fissure theory. In the eastern declivity along the contact with the Eastern sandstone on Keweenaw Point they see a "shore cliff" and not the "exposed side of a gigantic fault."¶

§ 9. Subsidence of Keweenawan beds.

In previous pages the origin and final deposition of the lava sheets of the Keweenaw series and of their interbedded conglomerates have been discussed with reference to the original horizontality of these beds. The position there taken involves also the subject of a subsidence of the beds near the basin center or axis, that Irving and Chamberlin contend was due to the weight of accumulating rock material.

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*Bull. U. S. G. S., No. 23, p. 115.

† F. and W., p. 68.

‡ Geol. Sur. Mich., I, Pt. III, pp. 96-98.

§ Rept. of Board of Geol. Sur. Mich., 1892, p. 164.

¶ Geol. Sur. Mich., I, Pt II, p. 5.

That there may have been a slow and progressive subsidence of the Keweenawan beds near the axis of the present Lake Superior basin is perhaps possible, but in view of the fact that the dips now seen along the shore adjacent to that axis are almost without exception within the limit of the angle of deposition of lava flows and of conglomerates, and that the dips of underlying beds in the Lake basin are inaccessible, there is no evidence of a convincing nature that would make such a subsidence necessary. The dip of the traps and interbedded conglomerate beds from older to younger, so far as yet observed, is, at its maximum, from near verticality in the former to a minimum of about 21° in the latter, 2500 feet below the surface, or to about 23° at the surface, and if by subsidence we are to understand a differential sinking of the beds, by which those parts of each formation near the basin center sank from time to time as other beds were deposited above them, we should expect to find at least in and near the central parts of the basin a steeper dip prevailing in the lower beds than in the higher ones, at points vertically above them. Thus far, in our deep mines, we have found no evidence to show such a relation of the strata, but what little evidence we have points in the other direction, that the dips are flatter as we go down vertically. It is as if, in addition to the natural decrease in the angle of deposition of the beds away from their point of origin, some force had been applied at the southern margin of the beds, which had the effect of lifting them—faulting, intrusion, or folding? I am aware that an apparent thickening of the beds from Portage Lake northeasterly, as suggested by Marvine, might be used as an argument in support of the above theory of subsidence, but in view of recent and more accurate observations* on the dips that were an essential part of Marvine's calculations, any far reaching conclusions from the latter should be accepted with reserve, for this thickening is, in the aggregate, of a trivial amount only, and may be due, for aught we know, to differential erosion.

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* The dip of the Allouez conglomerate at the Franklin Junior (Albany and Boston, Peninsula) mine was by Marvine supposed to be 52°. In reality it is but 48°. For the same bed at the Allouez mine Marvine used a dip of 46°. Mr. Fred Smith, agent of the mine, tells me the dip is 39°.

It may be observed here that an extensive sliding of the formations north and west in the Eagle River area may have brought thicker parts of beds horizontally lower and contributed to the apparent thickening northward of certain zones.

Anothar way in which subsidence may be regarded is as a simultaneous sinking of extensive areas of the series in a vertical or nearly vertical direction. This implies a kind of faulting that has seldom been observed on Keweenaw Point,* although apparently not uncommon on Isle Royale.

If by subsidence, however, we are to understand that phenomenon of gravity by which the beds of a series standing at high angles, owing either to their original deposition or to folding or to intrusion, should seek a state of equilibrium by a shearing motion along planes of weakness, whether between different beds or approximately parallel to their surfaces within a single bed, and the higher beds should slide over the lower in gradually decreasing curves until the equilibrium should be restored, then we have in the phenomena of Keweenaw Point many evidences of subsidence.

Such movements would expose to erosion at successive periods wider segments of the deeper and of the thicker beds as well, and especially of the lenses of acid rock, and we might expect to find in successive conglomerates abundant pebbles from the same bed or beds—perhaps also from rock masses intrusive in these beds, and in the earlier beds pebbles from older formations under them. Such movements doubtless agree in great part with those advocated by Irving and Chamberlin, but they do not necessarily presuppose a differential subsidence of all of those parts of the Keweenaw series along and near the axis of the present hydrographic basin of Lake Superior as due primarily to sedimentation—a subsidence that would imply a steepening of the dips of the older beds along that axis. This steepening might also be, and in some parts of the Keweenawan area probably was, increased by later intrusions near the margin of the series.

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*Capt. W. Clarke says there is an occurrence of this kind in the Copper Falls mine, with a throw of 22 feet.

§ 10. Junction line between the Keweenaw series and the Eastern sandstone.

The work of the Michigan Survey under Dr. Wadsworth showed that the line of contact between the Keweenaw series and the Eastern sandstone, although a curve which follows in a general way the trend of Keweenaw Point, is marked at several points by embayments more or less deep which interrupt the directness of the course of the contact. Where the outline of these embayments is coincident with the course of the conglomerates interbedded in the Keweenaw series near the contact, we have already suggested that the embayments may mark the former position either of eroded early intrusive, or of eroded pre-Keweenawan rocks, in either case representing the margin of a basin. The erosive agencies that wore away these ancient rock masses attacked also the edges of the later, steeply dipping Keweenawan beds, forming cliffs in some places and gentle slopes in others. Against these cliffs and on these slopes the Eastern sandstone was laid down. The present plane of contact between the traps and the Eastern sandstone is therefore variable, inclining sometimes westerly to northerly, sometimes easterly to southerly. It is not often exposed, but at some points between Wall Ravine (Sec. 20, T. 56, R. 32) and Sec. 6, T. 54, R. 33, south of Houghton, its prevailing hade or inclination seems to be west. At Wall Ravine according to Irving it is vertical near the surface, and lower down hades to the west. At Douglass Houghton Falls it is 30°, at Hungarian Falls 35°, west. At these and other points of contact the edges of the Eastern sandstone are much bowed, either up or down, a phenomenon ascribed to faulting. There seems to be no doubt that between the sandstones and the traps there has been a good deal of faulting at some points, notably where the plane of contact is highly inclined or where the traps overhang the sandstone. It is by no means so certain that where this plane dips gently eastward there are equally conclusive signs of faulting or that at every point where faulting has occurred, its amount has been equally great. We have only to recall the phenomena at Bare Hill and elsewhere on Bête Grise Bay where the mural character of the trap is not even as pronounced as it appears to have been in the Torch Lake area. The undercutting of the beds and the lakeward faulting of masses from the Keweenawan cliffs are plainly seen there, and the flexure of the abutting sandstone at several points at and near the contact is like that at other points further south and is exactly what might be expected to result from similar rock movements. In some areas of sandstone embayments, however, the sandstone clearly appears to be an overlap on the trap; in other cases, where the deeply dissected topography is strongly suggestive of a sandstone formation, it is not unusual to find at the heads of corraded channels large fragments of sandstone that may be and probably are remnants of a former edge of the Potsdam series. In these areas we must infer either that the eroded edges of the traps slope gently to the eastward, or, if they be of mural character, that the Eastern sandstone conceals them by extending above their steepest parts. Here, then, the mural contact with its pronounced fault features is not exposed. Any faulting we may observe between the eastward or southward sloping traps and the overlying sandstone is simply a contact phenomenon. The junction line, therefore, as evidence of a deep seated fissure in the Keweenaw series, must lose much of its importance. To use the terms "sandstone contact" and "fault line" as in this sense synonymous, is therefore incorrect.

If the mural character of the traps at points near the contact with the Eastern sandstone be considered as by itself evidence of a great fault in the trap series, one need only point to the Greenstone escarpment as an example of what erosive agencies have done in this area, and that, too, on very resistant rocks exposed to their attacks in a much less degree than the fractured rocks along the great Keweenawan cliff, and yet there is no evidence that the eastern face of the Greenstone ridge is a fault scarp.

The presence of masses of porphyry of indeterminable age and character, that is of rocks that may possibly be intrusive, along the contact between traps and sandstone might point to a line of weakness and to a deep seated fissure along that horizon, through which these rocks, if intrusive, reached their present position, but in the absence of other evidence such an inference can have the force of an inference only. Gilbert says of the Henry Mountain laccolitic intrusions that they mark "no discernible arrangement."* A part of the Little Montreal River felsite and the Bare Hill felsite show that the trap series was invaded at those points by intrusive masses, but thus far no evidence of a longitudinal fissure has been connected with these masses. The Allouez Gap and the Torch Lake porphyries, if intrusive, are not known positively to penetrate the trap series. If they were intruded along a line of weakness, that line may equally well be the contact plane between traps and sandstone.

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*Geology of the Henry Mountains, p. 2.

On the south shore of Lake Superior opposite the Keweenaw peninsula rises a mass of Archean granite, outliers of which are seen in the lake at Granite Island and at the Huron Islands, indicating the extension of this area north under the waters of the lake within the present area of the Eastern sandstone. The acid rocks found along the contact of the Eastern sandstone and Keweenaw series on Keweenaw Point, aside from the possibility of their being interbedded in the Keweenaw series, may be peripheral facies of this granite, or, like the granite near the Minnesota coast, according to some authorities,* they may be parts of a younger granite, intrusive between the Archean and the Keweenawan. In the latter case it may be to these intrusives that we must ascribe the final tilting and a large part of the slide-faulting of the Keweenawan; in the former, these phenomena may be simply the result of a differential elevation or subsidence of the two series along their plane of contact.

I have tried to emphasize the idea that the tendency to establish an equilibrium in the steeply dipping beds by slide-faulting need not be confined to the beds of the Keweenaw series, but if circumstances were favorable would probably extend to the contact planes between that series and intrusive masses, or between that series and an older one. The superimposition of a newer series on the latter, and their common movements are only incidents in the phenomena that began at an earlier period. Indeed, one might rather expect such a faulting to occur between an intruded and a steeply inclined intruding body more easily than between beds of a series that have become more or less firmly welded, and quite as easily along a steeply inclined contact between unconformable series. It is a matter of less consequence what may have been the ultimate cause of this movement, whether in an independent subsidence of the trap series, or in an emergence of the Archean.

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* J. Edward Spurr, The Iron-Bearing Rocks of the Mesabi Range in Minnesota, Geol. and Nat. Hist. Sur. Minn., Bull. No. X, p. 2; U. S. Grant, *ibid.*, 20th Ann. Rept., pp. 35-95, and 21st Ann. Rept., pp. 36, 37.

The evidence then seems to point to the early existence of an eroded line of steeply dipping and somewhat corrugated traps, against whose mural faces and over whose gentle slopes, respectively, the Eastern sandstone was laid down. Where the Keweenawan cliff overhung the sandstone, the weight of the former pressing on the more yielding sandstone would in time cause a deformation of its edges, the effects of which would be greatly increased, if segments of the trap were locally separated from the parent mass by normal faulting, as suggested by Wadsworth.* This would naturally follow where the Keweenawan cliff had been deeply undercut by wave action, and might more naturally occur than what I have termed slide-faulting, at points where the trap series was not steeply inclined, notably in the Torch Lake area. Indeed, the flatness of the dips in the trap series at points near the contact may in part be due to such a faulting, but that this cannot wholly account for the difference in structure between the lower part and the upper part of the series is manifest from the difference in character of the two horizons, as has already been pointed out.

The mural character of the contact plane between traps and sandstone and the contact phenomena between these two series do not therefore seem sufficient to establish the existence of a deep-seated fissure *in the Keweenaw series*, but leave open the alternate hypotheses of extensive erosion, and of faulting between the traps on the one side and the sandstone and the Archean on the other.

§ 11. Unconformity of Keweenaw series and Eastern sandstone at Douglass Houghton Falls.

As confirmatory evidence of the unconformity between traps and sandstone, as exhibited near Bare Hill, I append here a section (Fig. 11) at Douglass Houghton Falls, made by Mr. A. E. Seaman after an examination in 1889—the locality where such portions of the two series at the contact as were exposed appeared to be most nearly conformable. It thus appears that Mr. Seaman at that early date, by deeper excavation than had been made by previous investigators, was able to demonstrate, as will be evident to the unprejudiced, that the series there are not by any means conformable.

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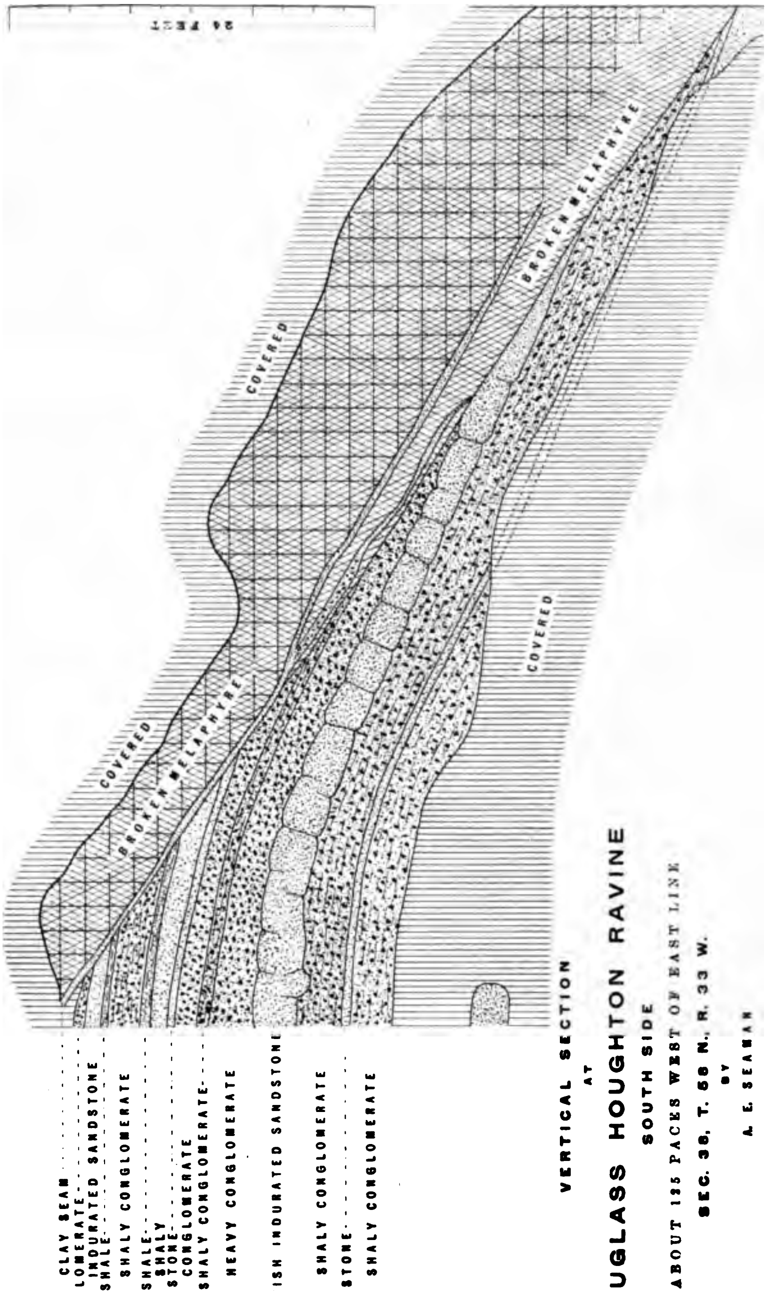
*Report State Board Geol. Sur., Mich., 1893, p. 164.



VERTICAL SECTION
AT
DOUGLASS HOUGHTON RAVINE
SOUTH SIDE
ABOUT 125 PACES WEST OF EAST LINE
SEC. 36, T. 58 N., R. 33 W.
BY
A. E. SEAMAN
1889

FIG. 11

The diagram indicates that there might have been a slight overthrust movement of the traps.

If the exposures in the Douglass-Houghton and Hungarian ravines were the only ones where the Eastern sandstone and the traps are seen in contact, the explanation that the former series underlies the latter conformably and that its former westward extension together with the overlying traps has been faulted normally against the sandstone on the east, would doubtless be plausible, but such an explanation is irreconcilable with the evidence at Bare Hill and elsewhere. On the other hand the evident superposition of the sandstone on the traps at Bare Hill calls for an explanation of the phenomena of Douglass Houghton ravine that shall be consistent with the later age of the sandstone. If it be objected by the opponents of the latter view that the sandstone along the contact may be of two different ages, one older and the other younger than the trap, it should seem that the burden of proof of the assertion must fall upon these objectors, for the sandstones agree in all essential characteristics and have thus far never been shown to be of different ages.

§ 12. Altitude of the Eastern sandstone.

The junction line of traps and sandstone, as appears by the foregoing pages, shows an overhanging of the traps in the Torch Lake area, as far north as Wall Ravine. The sandstone, if it formerly rose above the level of the trap escarpment and overlay it, has here been removed by erosion. This appears to be not improbable from remnants of sandstone on the eastward slope of the traps near the contact in the area immediately north of Wall Ravine, although it is quite true that such fragments might have been deposited there by glacial action. At Bête Grise Bay we find both classes of contact with evidence that goes to show that they were originally alike —the sandstone overlay the traps. In the latter area the sandstone is now found in place about 100 feet above Lake Superior; near Portage Lake it is more than 400 feet above the lake.[*] If the highest strata now found at these different points are in the same horizon, and if the dip of these strata continues at the same angle further southwest, it is probable that the sandstone formerly stood at a much higher elevation there, relatively to the traps. If, on the other hand, the highest sandstone strata near Portage Lake are above the horizon of those at Bare Hill, the sandstone formerly may have covered a large part of the northern area of Keweenaw Point.

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[*] Opposite the Belt mine, in Sec. 32, T. 51, R. 37, it is about 500 feet.

It is not impossible, therefore, that the reputed sandstone fragments formerly found back of Houghton, and cited by early geologists* as possibly *in situ*, were in fact at or near the place of their original deposition. These blocks have in great part long since been broken up and used for building purposes; only their extreme lower parts are left. One of them lay at what is known to be at or very near the junction line between sandstone and traps, 220 paces north, 1450 paces west, Sec. 31, T. 55, R. 33, on or near conglomerate bed No. 1 (Marvine's No. 2). The other was at 265 paces north, 485 paces west, Sec. 1, T. 54, R. 34. On digging through the remnants of this mass the latter was found to have under it about one inch of red sand, immediately beneath which lay trap in place. The sandstone here dipped at a small angle to the east. The absence of drift material between the sandstone and the underlying trap is evidence, so far as it goes, that the sandstone is not an erratic block. It is only half a mile west of the other so called fragment. Its altitude, 307 feet above Portage Lake, is a hundred feet lower than that of the Eastern sandstone less than three miles away. Thus there was nothing in the altitude of this block, or in its relations to the traps that militates against its having been *in situ*.

§ 13. Summary of hypotheses.

The facts gathered by the Survey and set forth in the preceding pages, together with observations made by previous investigators, have led to the formation of several hypotheses, of which the most recent may be briefly summed up as follows:

1. The eroded conformable downward extension of the Keweenaw series continues eastward under the Eastern sandstone of Keweenaw Bay. (Pumpelly and Brooks.)

2. The eastern face of the Keweenaw series, as now exposed, represents a fault scarp. The downthrown part of the series lies under the Eastern sandstone of Keweenaw Bay. (Irving and Chamberlin; Rominger.)

To these suggestions of previous observers I may add:

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* Geol. Sur. Mich., I, Pt. II, p. 3 and Pt. III, p. 96.

3. *a*—The irregularities in the lower beds of the Keweenaw series in the Portage Lake area, contrasted with the greater regularity of the higher part of the series, suggest that in this area near the contact between the Keweenaw series and the Eastern sandstone we are on the edge of an early-Keweenawan or pre-Keweenawan basin.

b—If the lower beds of the Keweenaw series near Portage Lake rested on the sides of a basin, the later beds of the series from here eastward lay at a higher altitude and, excepting those of the South Trap Range, were eroded in pre-Potsdam time together, possibly, with a part of the underlying Archean.

c—The porphyries found on Keweenaw Point at the contact between the Keweenaw series and the Potsdam sandstone may be in part either,—

(1) Marginal facies of the underlying Archean;

(2) Intrusive in the early Keweenawan;

(3) Early interbedded flows of the Keweenaw series; or,

(4) Remnants of late Keweenawan intrusions by which the eastern margin of the series was broken up and its degradation hastened.

The above may for the present be regarded as multiple working hypotheses.* The ultimate decision as to which hypothesis carries with it the greatest probability may await the result of future study in other parts of the range.

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*Cf. Chamberlin. Am. J. G., 1897. Vol. V, No. 7, p. 837.

CHAPTER VI.

RECENT WORK NEAR PORTAGE LAKE.

§ 1. The Franklin Junior.

With the end of the preceding chapter, bringing the work of the survey down to the close of 1897, this report was intended to finish, but during the two years that have elapsed since the latter was prepared for the press, some developments in mining have been made in the vicinity of Portage Lake that justify a departure from that plan, if only to make brief mention of them.

One of the earliest of these developments was the resumption of work at the Franklin Junior location, formerly known as the Peninsula and earlier still as the Albany and Boston, on Sec. 8, T. 55, R. 33. At this place a cupriferous bed supposed to be the Pewabic, 475 feet horizontally west of the Allouez conglomerate (dip 48°) has been opened by two shafts to the depth of some 900 feet. Details of the work on this bed are given in the report for 1897-98 of the Commissioner of Mineral Statistics, to which the reader is referred.

From a geological standpoint the most interesting work performed on the location by direction of Mr. Graham Pope, the enterprising agent, is the extension of the old cross-cut that runs from the Allouez conglomerate easterly. This and a drill hole were carried to a point some 250 feet east of a conglomerate that corresponds to the Kearsarge, known on the surface and in mine workings further north. This bed is thus seen to be the same as the conglomerate opened near the south quarter-post of Sec. 18, in the same township, known as the North Star (Pl. VIII), which, like the Kingston, must now as a separate bed be stricken from Marvine's list of conglomerates. In the same cross-cut are also exposed the Houghton and the Calumet conglomerates and the Osceola amygdaloid. All of the beds in the cross-cut are shown in the annexed section (Pl. IX), the widths having been measured with a tape by the Geological Survey. Their equivalent thicknesses and characters are noted in the following record:*

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* The difference in level between the two ends of the cross-cut is about 36 feet. An allowance for this was made in the aggregate thicknesses between conglomerates, but not in the separate beds The direction of the cross-cut is so nearly at right angles to the strike of the formation that no correction was thought necessary for the slight error thereby included in the computed thicknesses. The distances between conglomerates noted on Plate IX are approximate surface measurements.

RECORD OF CROSS-CUT.

9; **Allouez** (Albany and Boston) **Conglomerate;** ("The Slide" at Eagle River). Dip. 48°.

41 (31) 9-50: (S. 17275). *Melaphyre*, **amygdaloid;** calcitic. The upper 6 to 8 feet are much bedded and jointed as if by pressure (slipping?), and the thickest of the resulting layers, being rounded on the edges, look like lenticular boulders in a disintegrated cement.

67 (50) 50-117: (S. 17276). **Melaphyre,** ophite: feldspathic.

17 (13) 117-134: (S. 17277). *Melaphyre*, **amygdaloid,** calcitic.

21 (16) 134-155: (S. 17278). **Melaphyre,** ophite: feldspathic (?)

17 (13) 155-172: (S. 17279). *Melaphyre*, **amygdaloid.**

40 (30) 172-212: (S. 17280). **Melaphyre,** ophite.

18.5 (14) 212-230.5: (S. 17281). **Melaphyre,** altered, epidotic.

113 (85) 230.5-343.5: (S. 17282). **Melaphyre,** ophite. At 27 feet from the foot there is a seam of calcite and vein matter, from 2 to 4 inches thick.

6 (5) 343.5-349.5: (S. 17283). *Melaphyre*, **amygdaloid;** laumonitic.

48 (36) 349.5-397.5: (S. 17284). **Melaphyre,** ophite (?)

7 (5) 397.5-404.5; (S. 17285). *Melaphyre*, **amygdaloid.**

61 (46) 404.5-465.5: (S. 17286). **Melaphyre,** ophite.

38.5 465.5-504; (S. 17287). **Conglomerate,** acid.

1.25 504-505.25. **Sandstone.**

28 (51) (389) 505.25-533.25; (Ss. 17288-9). **Conglomerate,** basic. These three beds constitute the **Houghton** conglomerate. The upper 39 feet consist of rounded pebbles of felsitic and porphyritic rock, usually smaller than a goose egg, in a coarse cement of similar material, the whole being capped by three inches of flucean and separated from the underlying basic part of the bed by a foot of sandstone. Dip 49°-50°. The lower 28 feet form a typical example of an amygdaloidal or scoriaceous conglomerate; more or less rounded fragments of amygdaloid, carrying calcite, are embedded in a dark red fine grained cement that consists largely of quartz and iron oxide.

This conglomerate complex is of interest, in that it appears to mark a very sudden change in the conditions of erosion and deposition that contributed to its growth. The basic part of the bed appears to have been derived from the immediately underlying melaphyres, and the upper or acid part to have been transported from a more distant source—as is indeed evident from the smallness of its pebbles.

This conglomerate does not appear to have been cut by any of the Calumet shafts.

78 (60) 533.25-611.25: (S. 17290). **Melaphyre,** ophite.

15 611.25-626.25; (Ss. 17291-2). *Melaphyre,* **amygdaloid,** brecciated,
(12) calcitic, epidotic. Drift to north.

96 (73) 626.25-722.25; (S. 17294). **Melaphyre,** ophite.

5 (4) 722.25-727.25; (S. 17294). *Melaphyre,* **amygdaloid;** calcitic.

11.67 (9) 727.25-738.92; (S. 17295). **Melaphyre,** ophite.

17 738.92-755.92; (S. 17296). *Melaphyre,* **amygdaloid.** The last two
(13) amygdaloids with intervening melaphyre appear to be one bed.

53 755.92-808.92; (S. 17297). **Melaphyre,** ophite. Near the hanging
(41) this bed is somewhat seamed and carries laumonite, etc.

43 808.92-851.92; (S. 17298). *Melaphyre,* **amygdaloid.** Seamed,
(32) brecciated and decomposed; carries abundant calcite. Drift to north. On the south face of the cross-cut the rock appears quite compact. There is here a steep slide striking northeast and southwest, and dipping southeast, which might involve some faulting.

75.5 (58) 851.92-927.42; (S. 17300). **Melaphyre,** ophite.

41.5 927.42-968.92; (Ss. 17301-2). *Melaphyre,* **amygdaloid.** Near the
(32) hanging this bed carries calcite and laumonite in large patches. Drift.

78 (60) 968.92-1046.92; (S. 17303). **Melaphyre,** ophite.

9 (7) 1046.92-1055.92; (S. 17304). *Melaphyre,* **amygdaloid;** brecciated.

39 (30) 1055.92-1094.92; (S. 17305). **Melaphyre,** ophite.

27.5 (21) 1094.92-1122.42; (S. 17306). *Melaphyre,* **amygdaloid.**

6.5 (5) 1122.42-1128.92; (S. 17307). **Melaphyre,** ophite.

23.67 (18) 1128.92-1152.59: (S. 17308). *Melaphyre,* **amygdaloid.**

7.5 (6) 1152.59-1160; (S. 17309). **Melaphyre,** ophite.

26 1160-1186; (S. 17310). *Melaphyre,* **amygdaloid;** possibly with a
(20) thin layer of basic conglomerate on the hanging.

87 (66) 1186-1273; (S. 17311). **Melaphyre,** ophite.

5 (4) 1273-1278: (S. 17312). *Melaphyre,* **amygdaloid.**

62 (48) 1278-1340; (S. 17313). **Melaphyre,** ophite.

2 (2) 1340-1342; (S. 17314). Seam of coarse, altered ophite, carrying copper.

20 (15) 1342-1362; (S. 17315). **Melaphyre,** ophite.

7 (5) 1362-1369; (S. 17316). *Melaphyre*, **amygdaloid ;** highly altered, and very calcitic: bunchy.

54 (42) 1369-1423; (S. 17317). **Melaphyre,** ophite.

0.5 47 (36) (719) 1423-1470.5; (Ss. 17318-26). **Conglomerate.** The bed is capped by 4 inches of fluccan, and near the hanging is brecciated and seamed with calcite. For about 14 feet from the hanging it is largely of sandstone, changing in five feet to a more basic and scoriaceous character, which continues to the foot, terminating in a 6-inch seam of sandstone. This bed, according to accepted correlations must be the **Calumet** conglomerate, but the absence from it of rounded pebbles of acid rock is very noticeable, and shows a complete change of character in the few miles that intervene between this point and Osceola (N. E.).

3 (2) 1470.5-1473.5; (S. 17327). *Melaphyre*, **amygdaloid ;** bunchy.

116.5 (90) 1473.5-1590; (Ss. 17328-9). **Melaphyre,** *porphyrite;* feldspathic. At 50 feet from the hanging there is a slip on the north side of the cross-cut, dipping south-east, and carrying a half inch of fluccan.

53.5 (42) 1590-1643.5; (Ss. 17330-2). *Melaphyre*, *porphyrite*, **amygdaloid.** Contains frequent cavities, some of them 3 feet in diameter, filled with a soft, clayey decomposition product. Sp. 17332, from near the foot of the bed, is a feldspathic porphyrite of the Ashbed variety.

133 (103) 1643.5-1776.5; (Ss. 17333-6). **Melaphyre,** ophite. At 65 feet from the hanging there is a seam of calcite, one foot thick, which dips about 56° to the west. Near by there are several similar thinner seams, which show marked evidences of faulting movements.

17 (13) 1776.5-1793.5; (S. 17337). *Melaphyre*, **amygdaloid ;** carries quartz and epidote.

56 (44) 1793.5-1849.5; (S. 17338). **Melaphyre,** ophite verging on porphyrite. At the hanging is not well defined, but seems to pass gradually into the overlying amygdaloid, which is more or less shattered. A number of seams appear on the south side of the cross-cut, carrying laumonite and other alteration products. Dip of seams, about 45° east to southeast.

19 (15) 1849.5-1868.5; (S. 17339). *Melaphyre*, **amygdaloid.**

5 (4) 1968.5-1873.5; (S. 17340). **Melaphyre,** ophite.

20 (16) 1873.5-1893.5; (S. 17341). *Melaphyre*, **amygdaloid.**

156 (122) 1893.5-2049.5; (Ss. 17342, 17636). **Melaphyre,** ophite. The highest 38 feet of this bed, together with the three preceding beds, show more or less disturbance—seams and slips. The lower part of the bed is compact and massive, and coarsely lustre-mottled. In places it shows spheroidal parting on a large scale, some of the joints dipping north about 45°, but with no signs of slipping.

(451)

19 (15) 2049.5-2068.5; (S. 17637). *Melaphyre*, **amygdaloid.** This bed occupies the same relative position to the conglomerate next west of it, that the Osceola amygdaloid at Calumet does to the Calumet conglomerate, the vertical distances between the beds being, at the two localities, 451 and 449 feet, respectively. (See cross-section, Vol. V).

106 (83) 2068.5-2174.5; (S. 17638). **Melaphyre,** ophite.

6 (5) 2174.5-2180.5; (S. 17639). *Melaphyre*, **amygdaloid.** Not well defined at the foot, but passes gradually into the underlying bed.

75 (59) 2180.5-2255.5; (Ss. 17640-1). **Melaphyre,** ophite.

5 (4) 2255.5-2260.5; (S. 17642). *Melaphyre*, **amygdaloid.**

153 (121) 2260.5-2413.5; (S. 17643). **Melaphyre**, ophite.

10 (8) 2413.5-2423.5; (S. 17644). *Melaphyre*, **amygdaloid.**

107 (84) 2423.5-2530.5; (Ss. 17645-6). **Melaphyre**, ophite; shows some laumonitic seams near the foot, but is not brecciated to any great extent.

57.5 (45) 2530.5-2588; (S. 17647-50). **Conglomerate.** Capped by 16 inches of fluccan. Consists of medium sized to small, rounded pebbles of felsite and quartz porphyry with some amygdaloid, in a coarse matrix of similar material. The bottom of the bed consists of about 3 feet of sandstone, under which are 18 inches of an impure and very tough aggregate of calcite and ferruginous matter.

(863)

This bed corresponds to the Kearsarge conglomerate at the north, and to the North Star conglomerate at the south. Dip on fluccan, 52°-52½°.

2 (2) 2588-2590; (Ss. 17652-3). *Melaphyre*, **amygdaloid.**

51.5 (40) 2590-2641.5; (S. 17653). **Melaphyre.**

10 (8) 2641.5-2651.5. *Melaphyre*, **amygdaloid.**

166 (132) 2651.5-2817.5. **Melaphyre,** ophite.

21 (16) 2817.5-2838.5. *Melaphyre*, **amygdaloid.**

The last three measurements and part of the next preceding were obtained from the drill record.

The above section is the only one in the possession of the Survey that combines accuracy of horizontal measurements with trustworthy observations of the dip of the beds from point to point. These were seen to increase gradually from west to east, being 48° on the Allouez conglomerate, 49°-50° on the Houghton conglomerate, and 52½° on the Kearsarge conglomerate. The dip on the Arcadian bed, still further to the east, is reported by Mr. R. C. Pryor to be 56½°, so that the progressive increase may be assumed to continue to that point, but at a more rapid rate as we approach the lower part of the series.

Mr. Pope also uncovered, on the same location, Sec. 8, T. 55, R. 33, what is thought to be the **Kearsarge amygdaloid.** The rock closely resembles the amygdaloid found at the Wolverine mine, carrying large characteristic amygdules of calcite and feldspar, and being associated with doleritic melaphyres. This bed, according to Mr. Pryor, is about (2425-1117) 1,308 feet horizontally east of the Kearsarge conglomerate. If we assume for it a dip of 54¼°, consistent with the regularly increasing dip observed in the cross-cut, we derive a vertical thickness of about 1,087 feet for the strata between the Kearsarge conglomerate and the Kearsarge amygdaloid. From figures now at hand we can also estimate very closely the thickness between the amygdaloid and the Arcadian bed. Along the section line between Secs. 18-17 and 19-20, the horizontal distance between the north quarter-post of Sec. 18, very near which lies the foot of the North Star (Kearsarge) conglomerate, and the Arcadian bed (210 feet west of the north quarter-post of Sec. 19)—chained by Mr. Pryor—is 5,057 feet. According to Mr. Pryor, the strike of the Arcadian bed is N. 38° 49′ E. On Marvine and Emerson's map (Geol. Sur. Mich., I, Atlas, Pl. XIV b) the strike of the Allouez conglomerate is about N. 39° E., so that with this strike, applied also to the Kearsarge conglomerate, we find that the horizontal distance between the Kearsarge conglomerate and the Arcadian bed, at right angles to the strike $(5057 \times \overline{\sin 52^\circ\, 11' = 0.78998})$, is 3,995 feet. With an average dip of 55°, the vertical distance between these two beds is then $(3995 \times \overline{\sin 55^\circ = 0.81915})$ 3,273 feet. Deducting the vertical distance between the Kearsarge conglomerate and the Kearsarge amygdaloid—1,087 feet—the vertical distance between the latter and the Arcadian bed is thus about

2,166 feet. The assertion is thus negatived that the Kearsarge amygdaloid and the Arcadian bed are one and the same. We also see that the vertical distance between the Kearsarge amygdaloid and the Arcadian is about 700 feet greater than the computed vertical distance between the former bed at the Wolverine and the "inclusion" bed east of it. The latter, then, is probably not the continuation of the Arcadian-Isle Royale horizon, unless the formation at the Wolverine mine is much thinner than at the Arcadian mine. See Chapter IV, p. 77.

§ 2. The Isle Royale Consolidated.

On Atlas sheet XIV a, published with Vol. I, Geological Survey of Michigan, Marvine and Emerson laid down several beds on the south side of Portage lake, whose strike is supposed to correspond with that of the other beds of the series, and several veins whose strike appears to lie more to the west as they are followed south. Of these the principal, beginning on the east, are the "Mabbs vein," the "New vein," and a "Fissure vein" that crosses the old Huron location, on Secs. 1 and 2, T. 54, R. 34. The "Capen vein," east of the Isle Royale bed, appears to strike conformably with the latter, and seems to correspond with the "Jasper" bed found associated at several points with conglomerate No. 7 (Pl. X). The Survey is in possession of little information regarding the exact nature of these occurrences other than what has been gained by a very limited surface inspection of them, but some of them appear at least to partake of the nature of veins and show signs of brecciation, with a frequent filling of calcite between the rock fragments. This brecciation is noticeable also in the Isle Royale bed, which seems to be an amygdaloid, underlain by a bed whose upper part for several feet contains many apparent inclusions of amygdaloid rock, similar to the "inclusion" bed referred to in preceding pages. There is no doubt that in this area, in which the beds dip at angles between 50° and 60°, there has been a good deal of shearing, and while these "veins" are most frequently found to coincide with the amygdaloid portion of the lava beds, which were probably the planes of least resistance, this was not invariably the case. Immediately south of the old Huron location, the entire formation bends more westerly (from about S. 38° W. to about S. 58° W.), and if this change in strike is even in part the result of dynamic action, the plication may easily have been attended with fractures as we now see them in these "veins." Along the sides of Huron Creek, in Sec. 35, T. 55, R. 34, we find many examples of similar brecciation in the scoriaceous parts of the beds exposed there.

With our present limited knowledge it would be perhaps premature to express any decided opinion as to the extent and permanence of the copper deposits that occur between Portage Lake and the Porcupine Mountains, but we must bear in mind that this area, being one of steep dips, if shearing or slide-faulting preceded the deposition of copper and was the chief factor in preparing the way for it by producing seams and cavities, there must be a limit in depth to the effects of this shearing, and consequently in the deposits of mass and barrel copper that followed it. What the limit is we do not know. Where shearing is not confined to a plane of marked weakness, like a sandstone or the top of a conglomerate, but takes place in the more resistant trap, its effects—laterally also—may be distributed over several ill defined planes, each of irregular extent. This possibility should be borne in mind.

Of the geological relation of the Isle Royale to the Grand Portage bed the writer has as yet no information, his intention having been to treat all the mines south of Portage Lake in a future report.

§ 3. Correlation south of Portage Lake.

In Chapter V we have seen that the course of conglomerate No. 8, next east of the Isle Royale—Arcadian bed, probably makes a slight curve across Portage Lake (Plates VIII and X) being found at almost exactly the same distance from the latter bed on each side of the lake. This conglomerate has been traced by frequent outcrops to about 175 paces south of the north line of Sec. 11, T. 54, R. 34, just south of the old Huron mine on the west side of the Ontonagon road. About 860 feet east of it on the Huron Hill, conglomerate No. 6 has been traced almost equally far south. For three-quarters of a mile southwest of the above points, however, no traces of either bed have been seen until one reaches the low swampy ground that forms the headwaters of Huron Creek to the north, and of a small branch of the Pilgrim to the south. Here the road crosses a bed of conglomerate that has been traced over the crest of Frue Hill in Secs. 10 and 15, down to another branch of the Pilgrim on the Hennes farm about 400 paces east of the west quarter-post of Sec. 15. Here again for about 350 paces no more outcrops appear, although at an intermediate point on the last named stream many conglomerate blocks in the line of strike of the bed just followed from the northeast proclaim the nearness of the parent bed. Three-eighths of a mile beyond, on Five Mile Hill, three different conglomerate beds are exposed—two of them on the Baltic railroad—that pursue the same general course as the former bed nearly to the south line of Sec. 16. The highest* and lowest of these three beds are horizontally about 330 paces (871 ft.) apart, about the same interval that separates No. 6 and No. 8 on the Huron Hill. At this point two hypotheses face us. Either the formation is faulted some 330 paces, or the lowest of the three beds is the continuation of the conglomerate we have followed from the west side of Sec. 11. The invariable absence elsewhere in this area, of felsitic conglomerates for half a mile above No. 8 and the relative distances apart of the three beds on Five Mile Hill make it at least probable that we have here Nos. 6, 7 and 8. Moreover, in the Huron Creek hollow in Sec. 11 there is a large mass of conglomerate apparently in place, about 300 paces above the bed that is crossed by the road, and between the two, although apparently not at the proper interval in either case, there occur at least two thin beds of fine indurated sandstone, like the "jasper" that characterizes No. 7 nearer Portage Lake. However, waiving the question whether this conglomerate mass is in place, stronger evidence, perhaps, of the identity with No. 6, of the bed we have been tracing lies in the recurrence of characteristic amygdaloid conglomerates below it from Sec. 15 southwest, and in the apparent absence below it of any porphyry conglomerate that could correspond to No. 6, if this be No. 8. The reasons are not absolutely conclusive, but from all the facts that are now known, I feel fully justified in the belief that it is conglomerate No. 6 that has thus become prominent in Sec. 15, No. 8, with the possible exception of the isolated outcrop, being drift-covered or having wedged out until it reappears on Five Mile Hill.

The three porphyry conglomerate beds of Five Mile Hill were first opened by Capt. J. C. Hodgson in a series of trenches which are now to a great extent obscured by a growth of shrubbery. They have not been traced immediately south of Sec. 16, the range being heavily drift-covered for several miles in that direction, and few outcrops of any kind are visible beyond the Baltic mine until we reach the lower part of T. 53, R. 35. It is only by a critical study of the beds near Portage Lake that we may hope to recognize the different horizons when they reappear down the range.

In a former chapter attention was called to the irregularity of strike of the contact conglomerate on the south side of Portage Lake, the outcrops of this bed, together possibly with that of No. 2,* forming the sides and bottom of a bowl-shaped depression, capped by conglomerate No. 3, which appears to strike in close conformity with the overlying beds of the series. Bed No. 3 can be traced only for a short distance back of Houghton, beyond the old workings of the Mabbs vein in Sec. 1, T. 54, R. 34. The conglomerate lies upwards of 100 feet east of the Mabbs vein; the course of the latter is supposed not to be parallel with the strike of the former. The horizontal distance between conglomerate No. 3 and conglomerate No. 6, scaled from Marvine and Emerson's map, is about 2,060 feet, the horizontal distance between No. 3 and No. 4, being 1,300 feet. No dips have been noted here by the Survey on any of these lower beds, and in the following discussion we are obliged to rely on the assumed general conformity in strike of the beds above conglomerate No. 3, in order to arrive at any conclusions that shall have the force of probability.

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* This bed appears in reality to be a double conglomerate separated by a few feet of trap. There are surface indications of a similar condition in bed No 8 near its intersection with the old Isle Royale tramway (Pl. X.).

§ 4. The Baltic.

The Baltic mine is in an amygdaloid bed, whose strike according to Mr. Theodore Dengler, Mining Engineer of the Atlantic and Baltic mines, is N. 60° 30′ E. (magn.) This bed crosses the line between Secs. 20 and 21, T. 54, R. 34, about 200 feet north of the quarter-post. It shows some slight evidence of disturbance, in the nature of shearing or slide-faulting, in the presence of several small fissures that strike with the bed and are nearly vertical; they are filled with a carbonate of lime and carry some chalcocite. These fissures appear to wedge out at a short depth from the surface. Other irregular seams cross the rock, filled with calcite, this being also the usual filling of the amygdules. The latter are irregular in shape, and in places almost look as if they were secondary, i. e., pseudamygdules, due to the filling of irregular cavities or pores induced by chemical or by mechanical changes, or by both. The calcite is of earlier origin than the copper found associated with it, the latter showing the mould of the cleavage-and twin-planes in the former. On being exposed to weathering the calcite becomes yellow from a small percentage of iron in it. The dip of this bed is about 73° to the northwest.

About 114 feet southeasterly from the Baltic amygdaloid, we find a bed of porphyry conglomerate, beyond which extend trap and amygdaloid for about three-eighths of a mile to the edge of the Eastern sandstone. This conglomerate dips about 71° in the same direction as the amygdaloid. Above the conglomerate we find no other similar bed exposed in this immediate area until we reach No. 6, in Sec. 16. The horizontal distance between these two, allowing 20 feet for difference of altitude, is about 2,280 feet. In Sec. 15, next northeast, there is a fine exposure of conglomerate on the Hennes farm, which the Survey located by compass and by chaining, from the northeast corner of that section. It is about 2,440 feet horizontally southeast of No. 6, in the same section. These are the only two positive outcrops of porphyry conglomerate found by the Survey below No. 6 in this township west of Sec. 12, but it is noteworthy that near the southwest corner of Sec. 15, nearly in line with them, numerous fragments of conglomerate in the soil point to the probable nearness of the parent bed at that point.

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* The possibility is by no means excluded that No. 2 may, after all, be conformable with No. 3, instead of being the northward extension of No. 1, the contact conglomerate.

Going back to Sec. 1, we have seen that the horizontal distance between conglomerates No. 6 and No. 3, near the Mabbs vein, scaled from Marvine and Emerson's map, is 2,060 feet. If then the dips in the various strata that make up the zone from Portage Lake to the Baltic mine are even approximately uniform in the same bed, the Baltic conglomerate, the conglomerate on the Hennes farm south of the center of Sec. 15 and bed No. 3, must be one and the same bed. The fact that bed No. 4 is 1,300 feet horizontally above No. 3 at once negatives any suggestion that either of the two former outcrops can correspond to No. 4. They must be No. 3, or else some other bed very near its horizon—a bed of which we have no indications elsewhere, unless it be bed No. 2. The differences in the above horizontal measurements may be due to differences of dip in the strata opposite the several points considered. In any event they are, under the circumstances, not great enough to vitiate the correlation.

The bearing of this evidence upon the extension of the Baltic amygdaloid northeast can be appreciated at once. The possible existence of a slight fault or of a sudden curve in the formation near the west line of Sec. 15, by which the beds of Sec. 15 may lie somewhat more to the east than the corresponding beds in Sec. 16, may account for the length of the cross-cut made by the Atlantic exploration near the southeast corner of Sec. 16. If the line of disturbance, if there be such, lies to the west of this cross-cut, the distance to the conglomerate may be in reality greater than was expected. Even if no such line of disturbance exist, the cross-cut is apparently not yet far enough advanced to cut the lode. Upon the extension or non-extension of the latter to this point there can therefore as yet be nothing authoritative.

§ 5. The Atlantic.

The Atlantic mine, formerly called the South Pewabic, has commonly been thought to be in the Ashbed horizon, the same in which the Copper Falls, Arnold and some other mines on Keweenaw point have worked, and was correlated by Marvine and Emerson* with beds just below conglomerate No. 17, the Hancock West. The bed worked by the Atlantic Mining Co. is in part a melaphyre conglomerate,† being made up of fragments of amygdaloidal melaphyre in a matrix of fine but more or less angular basic sandy material, in places altered to epidote. The copper-bearing belt extends down into the unbroken amygdaloid. This and the underlying trap belong to the more basic lavas and have no immediate resemblance to the typical Ashbed rock as we find it on Keweenaw Point as far south as the Tamarack mine, other than in the fine dissemination of the copper which it carries. The Ashbed rock shows abundant greenish to reddish crystals of feldspar.

The work of the Survey together with some work recently done at my request by the Atlantic Company, through its Engineer, Mr. Theodore Dengler, enables me to suggest a possible correlation for the Atlantic bed that differs radically from those previously accepted, but appears for several reasons to be worthy of consideration. In appoaching this subject the great drawback has been, and to a great extent still is, the want of positive knowledge as to the dip of the rocks that underlie, drift-covered, the considerable area between the immediate valley of Huron Creek and the Atlantic mine.

The total difference of dip between the extreme beds to be considered —conglomerate No. 6 and the conglomerate next above the Atlantic bed—is, from the best obtainable data, about 4°, which corresponds very closely with the difference of dip across the same interval as far north as the Quincy mine on the opposite side of Portage Lake. From here further north, however, the difference of dip must soon increase materially, for opposite the Franklin Junior mine it is, as we have seen, $8\frac{1}{2}°$. Whether the same conditions exist at Calumet, the Survey has no means of knowing, for the cross-sections furnished us by the Calumet and Hecla and Tamarack Mining Companies show a uniform dip from one end to the other, that is, the dip of the Calumet conglomerate—37½°–38°. According to these cross-sections the interval between the Kearsarge and Allouez conglomerates is 2303 feet vertically, as against 1971 feet at the Franklin Junior. The formation at Calumet, then, *may* be thicker than it is at Portage Lake. At the Central mine we know that it *is* thicker. We see, then, that as we go north from Portage Lake the dips in the Keweenaw series grow flatter in the higher or younger beds, and in the aggregate the beds themselves in certain zones are probably thicker.

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* Geol. Sur. Mich. I. Atlas, XIV a.

† Pumpelly's description tallies well with this designation. Ibid. I, Pt. II, p. 77.

The tracing and accurate locating of the position, among others, of conglomerate No. 6, near Portage Lake, has also established the fact that while the course of this bed is somewhat irregular there is no reasonable ground to suppose that in this part of the series there has been transverse faulting other than of a trivial character, and hence the horizontal distances that we are able to scale from the map represent very closely the actual widths of the different belts between conglomerates. Thus, by applying the dips observed and those fairly deducible from them, we can ascertain the probable thickness of each of the different belts. Mr. Pope's valuable work in extending the cross-cut at the Franklin Junior affords a reliable standard of comparison, nearer Portage Lake than any previously known. The measurements derived from this cross-section show that the formation on each side of and immediately adjacent to Portage Lake is practically identical in thickness, but we have just seen that it is there probably less thick than at Calumet.

§ 6. Dips on Portage Lake beds.

1. Franklin Junior—Arcadian.

In the description of the cross-section at the Franklin Junior mine attention was called to the fact, just alluded to, that the dips observed on the different conglomerates in the cross-cut increase from 48° at the Allouez conglomerate (No. 15) to 52½° at the Kearsarge (No. 12). As previously stated, the dip of the Arcadian (Isle Royale) lode, still further east, is 56½°. This dip—of a copper-bearing zone—in a melaphyre might not agree with that of an interbedded conglomerate, but we have an independent observation in conglomerate bed No. 8 only 660 feet (horizontally) to the east of the Arcadian lode, which nearly agrees with the above figures, so that the fact is apparent that the gradual increase of dip eastward from the Allouez conglomerate holds good as far as conglomerate No. 8.*

In the absence of faults that would materially change the normal thickness of the series here, the extension eastward of the Franklin Junior cross-section from the Kearsarge conglomerate with a dip whose inclination is the average of 52½°–56½° = 54½°, may be accepted as accurate within narrow limits of error.

2. Isle Royale Consolidated.

On the south side of Portage Lake observations on conglomerate No. 12* (Kearsarge, Sec. 2, T. 54, R. 34), by Dr. Lane give dips ranging from 53° to 55½°, the average being about 54°. On the Isle Royale bed the dip according to Capt. W. E. Parnall, is 56°. These dips thus agree very closely with those of the equivalent horizons on the north side of the lake and are another indication that the correspondence of the two parts of the range immediately adjacent to the lake has not been disturbed to any great extent by the hitherto supposed fault in the lake.

3. Atlantic.

On the lowest conglomerate shown in this cross-section, bed No. 6, at a point in the S. W. ¼ of Sec. 11, T. 54, R. 34, a dip of 56° was measured, and a dip of 58° was noted on Frue Hill, in Sec. 10. The dip at the Atlantic mine at the other end of the cross-section is reported to be from 54° to 56°, an average of 55°.

Reducing horizontal width to thickness, we find the different zones as set forth in the following tables:

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* See p 105.

*Correlated by Marvine and Emerson, Mich. Geol Sur. I. Atlas, XIV a.

CROSS-SECTION, FRANKLIN JUNIOR TO ARCADIAN.

The measurements between beds are in feet, from footwall to footwall; those without parentheses denote *horizontal* width, those in parentheses denote *thickness*. No allowance is made for differences of altitude, which will not materially affect comparisons. Dips underscored have been actually observed.

Conglomerate beds.	6		8						12 Kearsarge.		13 Calumet.		14 Houghton.		15 Allouez.		16 Pewabic W.		17 Hancock W.
A. Douglass mine, Sec. 30, T. 55, R. 33.			57°	660† (552)	Isle Royale bed 56½°														
B. Arcadian mine, Sec. 20, T. 55, R. 33, to North Star, Sec. 18, T. 55, R. 33.					56½°		55° 3995† (3273)		53½°?										
C. St. Mary's, Sec. 18, T. 55, R. 33.																47°? 1500* (1097)		46°? 640* (460)	
1. Franklin Junior mine, Sec. 8, T. 55, R. 33.						(3273+552=3825)			52½°	1118† (863)	50½°	937† (719)	49½°	524+ (389)	48°				
2. Isle Royale Con.‡ mine, Sec. 1, T. 54, R. 34.		57°? 860† (722)		650† (542)	56°	2835 (2329)	No. 11 54½°	898 (729)	54°		1980 (1592)		53°?						

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† Numbers marked thus, †, indicate measured distances; all others are scaled from map. See Plates VIII, IX and X.

* Scaled from Marvine and Emerson's map.

‡ The beds noted in this cross-section were located and their identity was established by Marvine and Emerson under Pumpelly.

A comparison of the foregoing cross-sections, by zones, gives the following:

	Isle Royale Con.	Franklin Jr.-Arcadian.
Beds 8-12...............	3,600	3,825
Beds 12-14..............	1,592	1,582

The difference of elevation between beds 8 and 12 on the Isle Royale Consolidated (414–240) 174 feet, will reduce the vertical distance by 105 feet; that on the Arcadian (550–530) about 20 feet, will reduce the vertical distance between the same beds about 15 feet. In the Franklin Junior cross-cut the correction made for difference of altitude between beds 12 and 15 will increase the vertical distance 28 feet between beds 8 and 12. The corrected distances will then be

	Isle Royale Con.	Franklin Jr.-Arcadian.
Beds 8-12...............	3,495	3,838
Beds 12-14..............	1,592	1,582
Beds 8-14...............	5,087	5,420

These figures are probably within about 100 feet of accuracy,* and, in the absence of faults in the series, they point to a slight thinning of the formation southwest of the Franklin Junior. Measurements scaled from the map (Pl. X), between the Douglass and Quincy locations show that the horizontal distance at lake level between conglomerate No. 8 and the Allouez conglomerate (No. 15) is 6,660 feet, which with an average dip of (57°, 52°) 54½° makes the vertical distance there 5,422 feet. The corresponding interval at the Franklin Junior being 5,809 feet, and at the Isle Royale Consolidated (derived by subtracting interval 14–15 at the Franklin Junior from measurements at the Isle Royale Consolidated) 5,491 feet, we see that the thinning, if it actually exists, is between the Franklin Junior and the Quincy, and that the formations, in thickness, as well as in dip, agree very closely on each side of and immediately adjacent to Portage Lake. This thinning, then, so far as the evidence goes, may not extend further south than Portage Lake.

If, now, we construct a cross-section on similar lines to the above, from the Atlantic mine to conglomerate No. 6 in Sec. 15, T. 54, R. 34, lettering the three conglomerate beds† in Secs. 4 and 9 (Atlantic) A, B and C, from the highest down, we get the following:

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* Scaled from the map, Plate X, the total distance from No. 8 to No. 14 on the Isle Royale Consolidated is 5,096 feet *minus*, instead of 5,192 feet.

† The locations of these conglomerates were determined by Mr. F. McM. Stanton.

Conglomerate beds	6		8		C (13)		B (14)		A (15)
3. Atlantic mine. Secs. 4 and 9, T. 54. R. 34, to Sec. 15, T. 54, R 34.		58°		57°		56°		55°	
						1205		571	
		(722)[*]		(5560--722=4838)		(999)		(468)	

We see, on examination of these figures, that the zone 8—C, 4838 feet, as computed, is just 150 feet thicker than the zone 8—13 of the Franklin Junior–Arcadian cross-section, or not greater than what we should expect would be the thickness of the same zone at Calumet. On the other hand, it is 375 feet thicker than the corresponding zone opposite the Isle Royale Consolidated, or 250 feet thinner than the zone 8—14 at the last point (5087 feet). That the bed C cannot well be No. 14, the Houghton conglomerate, is apparent when we try to reconcile the positions of beds B and A [†] with those of conglomerates next above the Houghton at other points. This bed C, then, should be the Calumet conglomerate, and if the dips used in our computations be correct, the formation south of Portage Lake may thicken instead of continuing to grow thinner. In order to bring this bed into line with the Allouez conglomerate—which it has been supposed to be—we should have to use a dip of 66° or more on conglomerate No. 6 at Frue Hill, and while there is indeed evidence that the dip on this bed is probably nearly that steep on Five Mile Hill, a mile further southwest, we have no evidence that the same conditions obtain at the point of our cross-section. In candor, however, I must say that the dip assumed for that point has not been determined beyond a reasonable doubt.

A circumstance of some importance that bears on the possible identity of conglomerate C with the Calumet lies in the fact that at about 440 feet vertically under this bed, on the Atlantic location, occurs an amygdaloid bed that carries considerable copper. This may be merely a coincidence, but at Calumet and at the Franklin Junior the Osceola amygdaloid lies 450 feet vertically under the Calumet conglomerate.

If the above considerations and conclusions are just, the Atlantic bed lies between the Houghton and the Allouez conglomerates.[‡] There is at least enough of probability in this conclusion to warrant a search for the Quincy bed in ground west of the Atlantic. A more positive statement would perhaps be unwarranted, for in a drift-covered area it is impossible to know whether exceptional conditions exist in the hidden rocks, by which the most careful calculations may be vitiated, and in the present case I have been forced to conclude that conditions may have been reversed that held from Calumet to Portage Lake.

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[*] Derived from cross-section No. 2. The altitude at the Atlantic mine (436 feet above Portage Lake) is about the same as that on conglomerate No. 6 on Frue Hill.

[†] The intervals respectively between C and B and B and A correspond closely with those respectively between beds 15 and 16 and 16 and 17 at the St. Mary's, but in view of the other facts noted in the text, undue weight should not be given to this circumstance.

[‡] The interval between them here, 468 feet, is 87 feet greater than that at the Franklin Junior, but the latter is abnormally small. See Proc. L. S. Min. Inst., 1895, p. 76.

If the conglomerate that I have assumed to be No. 6 were in reality No. 8, bed C would then occupy a position about 250 feet short of that of No. 15 (the Allouez) at the Franklin Junior, but this is a correlation for the older beds that I am loath to admit.

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GEOLOGICAL SURVEY OF MICHIGAN

VOL. VI

PART II—APPENDIX

THE CRYSTALLIZATION OF THE CALCITE

FROM THE

COPPER MINES OF LAKE SUPERIOR

BY

CHARLES PALACHE

ACCOMPANIED BY SIX PLATES

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LAKE SUPERIOR CALCITES.

INTRODUCTION:—The copper mines of the Keweenaw Peninsula on the southern shore of Lake Superior have long been noted among mineralogists for their rich product of crystallized minerals, among which, after the native copper, calcite easily comes first in the interest and beauty of its specimens.

The present paper presents the results of an extended study of a large series of these calcite crystals. Such a study seemed desirable in view of the fact that the extremely rich crystallographic material here offered had been almost entirely neglected by American students; scattered papers in French and German contain with one exception the only published descriptions of Lake Superior calcites, and while these are excellent as far as they go, they were based on limited material and cover but a small portion of the field.

The material at the author's disposal for this study amounted in all to more than two hundred crystals, and he feels warranted in believing that among them were specimens of all the more important crystal types that have been found in the region. The bringing together of so large and fine a collection of these calcites was made possible only by the liberality of the owners and directors of many mineral cabinets, who allowed the author the free use of the material in their possession, and he desires here to express his thanks and obligations to all those who thus aided him. The following list will show the sources of the studied material. It includes only the number of the crystals actually measured; at least as many more were in hand and studied with less detail.

From the collection of:

C. S. Bement	10	crystals.
Brush Cabinet, Yale University	3	"
J. N. Cox	1	"
B. F. Chynoweth	1	"
G. L. English & Co.	4	"
L. L. Hubbard	22	"
Harvard Mineralogical Museum	21	"
J. H. Lathrop	5	"
R. Pumpelly	12	"
W. D. Schoonmaker	1	"
J. H. Sears	1	"
H. L. Smyth	2	"
Delia M. Stickney	1	"
U. S. National Museum	1	"
Geo. Vaux, Jr.	5	"
W. B. Whiting	21	"
Measured crystals	111	

To Dr. L. L. Hubbard, the author owes a special measure of thanks for his unceasing kindness in supplying material as well as advice and assistance essential to the success of this study; and acknowledgments are due to Mr. W. W. Stockly for the care involved in the final preparation of the plates for publication.

In all of the crystallographic work the author has had the constant advice and aid of Professor Victor Goldschmidt of Heidelberg, for which he would here express his deep obligations.

LITERATURE:—The earlier writers who studied the Lake Superior copper mines make frequent mention of the abundant and beautiful crystallizations of calcite found in the veins; and the fact that these crystals were from the first valued and preserved by collectors is witnessed by the specimens in many collections bearing dates almost as far back as the beginning of mining in the region. But none of these earlier references to the Lake Superior calcites contain any crystallographic descriptions, save the most vague and general, and we are indebted to the German mineralogist, vom Rath, for the first detailed study of crystals from this locality. In a paper * published in 1867

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* G. vom Rath, Mineralogische Mittheilungen. Poggendorf's Annalen, vol. 132, 1867, p. 387, vol. 152, 1874, p. 17.

he describes and figures four crystals which exhibit very well the commoner habits of calcite of this region; and his remarks on the dominant forms and on the twinning of these crystals have been fully confirmed by later studies. He published further a description of a complex twin crystal in 1874.

The next study of these crystals was made by Hessenberg* in 1870. He desçribes two combinations, of forms for the most part new and having highly complicated symbols. The crystals, which appear to have been rather poorly adapted to measurement, were afterwards re-examined by Irby† who altered and simplified many of the symbols found by Hessenberg, but found additional forms of quite as complex a character. But few of these forms of Irby's have been observed a second time and are probably to be considered as vicinal.

Des Cloizeaux figured a crystal of Lake Superior calcite in his Manuél de Minéralogie, Vol. 1, plate XLV, published in 1862; the text in which the figure is briefly described did not appear however until 1874. The crystal was similar to some of vom Rath's.

In 1891, Césaro‡ described a complex crystal with some rare planes.

In 1895 Palache§ described a specimen preserved in the Munich cabinet. A reproduction of his figure is given in figure 8, plate XII, and will be referred to later.

Thus in all, up to the present time, there have been described and figured ten combinations of Lake Superior calcites, exhibiting about twenty-eight well established forms and a number of more or less uncertain ones.

Occurrence of the Calcite:—Calcite occurs abundantly as a vein mineral throughout the copper deposits of Lake Superior. Its deposition appears not to have been confined sharply to any one period of vein filling, but continued through several stages of the process.

According to Pumpelly,‖ who gave special attention to the paragenetic relations of the various minerals, there were two well marked periods of calcite deposition toward the end of the filling of both fissure veins and amygdaloidal cavities, between which was a period of copper and datolite deposition; while in rare cases there seems to have been an earlier calcite deposit, preceding almost wholly the copper deposit.

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* Hessenberg, Mineral. Notizen. Abhandlungen der Senckenbergischen naturforschenden Gesellschaft. Band VII, 1870, p. 257.

† J. R. McD. Irby. On the Crystallography of Calcite. Inaugural Dissertation, Bonn, 1878. Abstract in Zeitschrift für Krystallographie. Vol. 3. 1879.

‡ Césaro, Calcite from Lake Superior. Annales de la Soc. geol. Belgique. 1891, Vol. 18.

§ C. Palache, Calcite von Lake Superior, Zeitschrift für Krystallographie. Vol. XXIV, 1895, p. 589.

‖ Raphael Pumpelly. The Paragenesis and Derivation of Copper and its Associates on Lake Superior. American Journal of Science, Vol. II, 1871. See also Geol. Sur. Mich., I, Pt. II, p.19.

The double period of calcite deposition is well shown in the frequent crystals whose growth has been interrupted by the deposit of a coating of copper, the subsequent enclosure of which by a second generation of calcite material in perfect crystallographic continuity with the first often produces "shadow crystals" of great beauty. This interruption in the growth of the crystal is generally marked in addition by a decided change in habit, due to the altered conditions of growth during the two periods. Figure 15, Plate XIV, shows such a "shadow crystal," the inner crystal, outlined by copper, bounded by a positive scalenohedron and the basal plane, the outer one showing only negative scalenohedrons. The cleavage in such a crystal, however, extends unbroken through the whole mass, except for the slight irregularity apt to be caused by the thin layer of tough copper.

In a large number of cases it is certain that calcite was the last mineral to crystallize in the deposit, and to this fact we owe in large measure the great abundance of splendid crystals, the open spaces giving free opportunity for complete crystal development.

It is unfortunate for our study of these calcites that in very many cases the exact locality or mine from which a crystal was obtained has not been recorded. The variety in mode of formation of the deposits that have been worked for copper in this region would give ground to hope that had more data been available it might have proved possible to trace a definite relation between them and the habit of the crystals formed under their various influences. The crystal habit varies in a striking manner, but we are hardly justified in saying more than that, while the crystals exhibit well-marked types in certain districts or groups of mines, slight dependence upon the nature of the deposit has been recognized. Reference to these "district types" will be found below under the description of crystal combinations.

General Description of the Calcite:—The calcite crystals are for the most part transparent, the colorless ones being sometimes absolutely pellucid and flawless even when quite large. The colorless condition is perhaps the most common; but very many are tinted a pale to deep wine yellow, and inclusions of native copper give to some a reddish color. Where the copper is in finely divided scales or spangles it makes a charming "aventurine" effect. Some of the "shadow crystals" mentioned above have the inner crystal of milky white material, while the exterior is colorless, thus heightening the contrast marked by the copper deposition. This milky condition is very common and characteristic in crystals from the Pewabic-Quincy lode, but is otherwise not common in the region. One crystal from the Bement collection was quite black and opaque through abundant inclusions of a powdery black material of undetermined nature.

It is rare to find a crystal other than the most minute in which cleavage cracks are not more or less developed, and the iris colors induced along these planes often add largely to the beauty of the specimen, expecially in water-clear crystals.

The crystal planes are for the most part of great perfection and high lustre, even in large crystals. Certain forms, however, tend to unevenness through striation, and etching phenomena are by no means rare. A discussion of these characters will be found below.

As would be expected there is a wide range in the size of the crystals, but they by no means rival those from other localities in the attainment of extremely large dimensions. The largest crystal from Lake Superior known to the writer is now in the Harvard Mineralogical Museum; it measures about six inches in height and in diameter. Crystals of from two to four inches in height are by no means uncommon and are often remarkable, as well for the perfection of their planes as for the symmetrical development of the many forms frequently found in combination upon them.

One character which lends these crystals a peculiar value both to the crystallographer and to the mineral collector is their tendency to develop as isolated crystals. Often implanted on a sheet of copper or on the wall of a cavity lined with copper or quartz, sits a single symmetrical crystal. Again the calcites are found implanted on delicate threads of copper, giving opportunity for the growth of doubly terminated crystals of more than ordinary completeness. Such perfect forms are, however, of exceptional occurrence and incrustations with occasional crystals rising from their midst, or drusy coatings are the rule.

CRYSTALLIZATION:—The table on the following pages contains a list of all the forms observed on crystals of calcite from Lake Superior. The letters there used to designate the forms are those used by Goldschmidt in the Index der Krystallformen der Mineralien, this being the only list published in which a complete enumeration of the multitude of calcite forms, together with letters for each one, has been attempted. In the column headed "D" are given the letters used by Dana in the System of Mineralogy, 1892, for such forms as appear in his incomplete list. In assigning letters to the many new forms found in this investigation, Goldschmidt's table, on page 141 of the above work, has been used. These letters* have been used both in the gnomonic projection plate and in the crystal drawings. The three columns containing for each form the symbol according to Goldschmidt, Naumann and Bravais-Miller, will facilitate reference to most works containing descriptions of calcite. The Goldschmidt symbol here given is that found under the heading "G_2" in his work.

All the forms named were observed by the author except where noted in the last column, which contains also the names of other observers who have described any of the forms. The word *new* opposite any form indicates that it is new to calcite.

A supplementary list contains all forms recorded for this region which can not be regarded as well established or have been called in question. Forms such as those of Hessenberg which have been revised by later study of the same crystals have not been included.

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* In the case of the letter *θ* a different type has been used in text and plates.

Table of forms of Lake Superior Calcite.

No.	Letter		Symbol			Remarks
	Gld. Pal.	D.	Goldsch.	Naumann	Bravais-Miller	
1.	o	c	0	0R	0001	vom Rath, Hessenberg
2.	b	m	∞	∞R	$10\bar{1}0$	
3.	a	a	∞0	∞P2	$11\bar{2}0$	vom Rath
4.	ζ	ζ	$\frac{5}{2}$∞	∞R2	$31\bar{4}0$	
5.	θ	—	4∞	∞R3	$21\bar{3}0$	
6.	ψ	—	$\frac{4}{3}$∞	∞R$\frac{11}{9}$	$10.1.\overline{11}.0$	new
7.	π	π	10	$\frac{2}{3}$P2	$11\bar{2}3$	
8.	λ	—	20	$\frac{4}{3}$P2	$22\bar{4}3$	
9.	ν	—	30	2P2	$11\bar{2}1$	new
10.	ω	—	$\frac{16}{9}$0	$\frac{32}{9}$P2	$16.16.\overline{32}.9.$	new
11.	z·	ω	+28.28.	+28R	$28.0.\overline{28}.1.$	
12.	s·	ν	+13.13.	+13R	$13.0.\overline{13}.1.$	
13.	r·	θ	+10.10.	+10R	$10.0.\overline{10}.1.$	vom Rath
14.	m·	M	+4	+4R	$40\bar{4}1$	vom Rath, Hessenberg
15.	k·	k	+$\frac{5}{2}$	+$\frac{5}{2}$R	$50\bar{5}2$	vom Rath, Des Cloizeaux
16.	R·	—	+2	+2R	$20\bar{2}1$	new
17.	p·	r	+1	+R	$10\bar{1}1$	vom Rath, Hess., Des Cloiz.
18.	δ·	e	—$\frac{1}{2}$	—$\frac{1}{2}$R	$\bar{1}012$	vom Rath, Hess., Des Cloiz.
19.	θ· *	—	—$\frac{7}{8}$	—$\frac{7}{8}$R	$\bar{7}078$	
20.	λ·	L	—$\frac{8}{7}$	—$\frac{8}{7}$R	$\bar{8}087$	Irby
21.	ξ·	A	—$\frac{4}{3}$	—$\frac{4}{3}$R	$\bar{4}043$	
22.	π·	Π	—$\frac{7}{5}$	—$\frac{7}{5}$R	$\bar{7}075$	vom Rath, Des Cloizeaux
23.	ρ·	h	—$\frac{3}{2}$	—$\frac{3}{2}$R	$\bar{3}032$	
24.	σ·	—	—$\frac{11}{7}$	—$\frac{11}{7}$R	$\overline{11}.0.11.7.$	
25.	τ·	—	—$\frac{13}{8}$	—$\frac{13}{8}$R	$\overline{13}.0.13.8.$	
26.	φ·	f	—2	—2R	$\bar{2}021$	vom Rath, Des Cloizeaux
27.	ω·	—	—$\frac{11}{4}$	—$\frac{11}{4}$R	$\overline{11}.0.11.4.$	
28.	Γ·	ψ	—3	—3R	$\bar{3}031$	
29.	Δ·	χ	—$\frac{7}{2}$	—$\frac{7}{2}$R	$\bar{7}072$	vom Rath, Des Cloizeaux
30.	Π·	d	—8	—8R	$\bar{8}081$	vom Rath

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* In the figures the other form of *theta* is used.

Table of forms of Lake Superior Calcite.—Continued.

No	Letter		Symbol			Remarks
	Gld. Pal.	D.	Goldsch.	Naumann	Bravais-Miller	
31.	Σ·	Σ	−11.11.	−11R	$\overline{11}.0.11.1.$	
32.	u:	—	$-\frac{11}{13}\frac{2}{13}$	$-\frac{2}{13}R4$	$\bar{5}.\bar{3}.8.13.$	new
33.	v:	Ψ	$+1\frac{1}{5}$	$+\frac{1}{5}R\frac{11}{3}$	$7.4.\overline{11}.15.$	vom Rath
34.	g:	G	$+1\frac{1}{3}$	$+\frac{1}{3}R\frac{7}{3}$	$52\bar{7}9$	
35.	w:	w	$+1\frac{2}{5}$	$+\frac{2}{5}R2$	$31\bar{4}5$	vom Rath
36.	f:	—	$+1\frac{5}{11}$	$+\frac{5}{11}R\frac{9}{5}$	$7.2.\bar{9}.11.$	
37.	e:	E	$+1\frac{1}{2}$	$+\frac{1}{2}R\frac{5}{3}$	$41\bar{5}6$	
38.	b:	—	$+1\frac{2}{3}$	$+\frac{2}{3}R\frac{4}{3}$	$71\bar{8}9$	vom Rath only
39.	a:	—	$+1\frac{7}{10}$	$+\frac{7}{10}R\frac{9}{7}$	$8.1.\bar{9}.10.$	vom Rath only
40.	G:	—	$+\frac{11}{5}1$	$+R\frac{9}{5}$	$72\bar{9}5$	
41.	H:	λ	$+\frac{5}{2}1$	$+R2$	$31\bar{4}2$	
42.	J:	—	+31	$+R\frac{7}{3}$	$52\bar{7}3$	
43.	K:	v	+41	+R3	$21\bar{3}1$	vom Rath, Des Cloizeaux
44.	L:	—	$+\frac{35}{8}1$	$+R\frac{13}{4}$	$17.9.\overline{26}.8.$	
45.	M:	—	+51	$+R\frac{11}{3}$	$7.4.\overline{11}.3.$	
46.	N:	Υ	$+\frac{11}{2}1$	+R4	$53\bar{8}2$	
47.	P·	—	$+\frac{13}{2}1$	$+R\frac{14}{3}$	$17.11.\overline{28}.6.$	new
48.	P:	y	+71	+R5	$32\bar{5}1$	
49.	T:	ζ	+10.1	+R7	$43\bar{7}1$	vom Rath
50.	U:	μ	+13 1	+R9	$54\bar{9}1$	vom Rath
51.	Π:	—	+43	$+3R\frac{11}{9}$	$10.1.\overline{11}.3$	new
52.	Γ:	—	$+\frac{19}{4}4$	$+4R\frac{9}{8}$	$17.1.\overline{18}.4.$	new
53.	Δ:	—	+54	$+4R\frac{7}{6}$	$13.1.\overline{14}.3.$	new
54.	Σ:	—	$+\frac{26}{5}4$	$+4R\frac{6}{5}$	22.2.24.5.	new
55.	Θ:	—	$+\frac{16}{3}4$	$+4R\frac{11}{9}$	$40.4.\overline{44}.9.$	new
56.	Φ:	—	$+\frac{11}{2}4$	$+4R\frac{5}{4}$	$9.1.\overline{10}.2$	new
57.	Λ:	—	$+\frac{40}{7}4$	$+4R\frac{9}{7}$	$32.4.\overline{36}.7.$	new
58.	Ξ:	—	+64	$+4R\frac{4}{3}$	14.2.16.3.	
59.	Ψ:	—	+74	$+4R\frac{3}{2}$	5161	
60.	λ:	—	+10 4	+4R2	$62\bar{8}1$	

Table of forms of Lake Superior Calcite.—Concluded.

No.	Letter		Symbol			Remarks
	Gld. Pal.	D.	Goldsch.	Naumann	Bravais-Miller	
61.	U	--	$+62$	$+2R\frac{7}{8}$	$10.4.\bar{14}.3.$	new
62.	𝔚:	Q	$+\frac{32}{5}\,\frac{8}{5}$	$+\frac{8}{5}R3$	$16.8.\bar{24}.5.$	
63.	P	—	$+92$	$+2R\frac{10}{8}$	$13.7.\bar{20}.3.$	new
64.	M	—	$+\frac{16}{5}\,\frac{4}{5}$	$+\frac{4}{5}R3$	$8.4.\bar{12}\,5.$	new
65.	Z	—	$+\frac{8}{5}\,\frac{4}{5}$	$+\frac{4}{5}R\frac{5}{3}$	$16.4.\bar{20}.15.$	new
66.	N	—	$+\frac{20}{11}\,\frac{8}{11}$	$+\frac{8}{11}R2$	$12.4.\bar{16}.11.$	new
67.	𝔴:	- -	$+\frac{5}{2}\,\frac{1}{2}$	$+\frac{1}{2}R\frac{11}{3}$	$7.4.\bar{11}.6.$	new
68.	𝔟	- -	$+\frac{14}{5}\,\frac{3}{5}$	$+\frac{3}{5}R\frac{31}{9}$	$20.11.\bar{31}.15.$	new
69.	𝔞	- -	$+\frac{25}{7}\,\frac{6}{7}$	$+\frac{6}{7}R\frac{28}{9}$	$37.19.\bar{56}.21.$	new
70.	b:	r	$-\frac{11}{4}\,\frac{1}{2}$	$-\frac{1}{2}R4$	$\bar{5}\bar{3}84$	vom Rath, Des Cloizeaux
71.	𝔉:	p	$-\frac{16}{5}\,\frac{4}{5}$	$-\frac{4}{5}R3$	$\bar{8}.\bar{4}.12.5.$	vom Rath, Irby, Des Cloiz.
72.	F	—	$-\frac{7}{2}1$	$-R\frac{8}{3}$	$\bar{11}.\bar{5}.16.6.$	new
73.	A	·	$-\frac{26}{7}\,\frac{8}{7}$	$-\frac{8}{7}R\frac{5}{2}$	$\bar{14}.\bar{6}.20\,7.$	new
74.	I	—	$-\frac{31}{8}\,\frac{5}{4}$	$-\frac{5}{4}R\frac{12}{5}$	$\bar{17}.\bar{7}.24.8.$	new
75.	Y	—	$-\frac{56}{13}\,\frac{20}{13}$	$-\frac{20}{13}R\frac{11}{5}$	$\bar{32}.\bar{12}.44.13.$	
76.	𝔭:	x	-52	$-2R2$	$3\bar{1}41$	vom Rath, Des Cloizeaux
77.	B	—	$-\frac{64}{11}\,\frac{28}{11}$	$-\frac{28}{11}R\frac{13}{7}$	$\bar{40}.\bar{12}.52.11.$	new
78.	𝔛:	N	-84	$-4R\frac{5}{3}$	$\bar{16}.\bar{4}.20.3.$	vom Rath
79.	C	—	$-\frac{18}{7}\,\frac{4}{7}$	$-\frac{4}{7}R\frac{10}{3}$	$\bar{26}.\bar{14}.40.21.$	Irby
80.	I·	—	$-3\frac{7}{8}$	$-\frac{7}{8}R\frac{55}{21}$	$\bar{38}.\bar{17}.55.24.$	new
81.	D	—	$-\frac{7}{2}\,\frac{5}{4}$	$-\frac{5}{4}R\frac{11}{5}$	$\bar{8}.\bar{3}.11.4.$	new
82.	E	—	$-\frac{7}{4}\,{}_{2}\frac{7}{2}$	$-{}_{2}\frac{7}{2}R4$	$\bar{35}.\bar{21}.56.44.$	new
83.	K	—	$-\frac{18}{8}\,\frac{5}{4}$	$-\frac{5}{4}R\frac{6}{5}$	$\bar{11}.\bar{1}.12.8.$	new
84.	𝔡	—	$-\frac{44}{31}\,\frac{32}{31}$	$-\frac{32}{31}R\frac{3}{2}$	$\bar{36}.\bar{4}.40.31.$	new
85.	𝔠	—	$-\frac{28}{17}\,\frac{16}{17}$	$-\frac{16}{17}R\frac{3}{2}$	$\bar{20}.\bar{4}.24.17.$	new
86.	𝔣	—	$-\frac{32}{13}\,\frac{14}{13}$	$--\frac{14}{13}R\frac{13}{7}$	$\bar{20}.\bar{6}.26.13.$	new
87.	𝔤:	K	-21	$-R\frac{5}{3}$	$\bar{4}\bar{1}53$	

Note: The paper of Césaro op. cit was not accessible to the author and the forms observed by him are therefore not included above.

Supplementary List of uncertain forms of Lake Superior Calcite.

No.	Letter		Symbol			Remarks
			Goldsch.	Naumann	Bravais-Miller	
1.			+18.18	+18R	$18.0.\bar{18}.1.$	vom Rath Probably 19 R or $\frac{35}{2}$ R (Golds.), either of which conforms better with the series of rhombohedron forms.
2.			$+\frac{15}{6}\ \frac{1}{2}$	$+\frac{1}{2}R^{\frac{11}{3}}$	$7.4.\bar{11}.6.$	Irby. Dull face, approx. readings.
3.			$+\frac{70}{27}\ \frac{14}{27}$	$+\frac{14}{27}R^{\frac{11}{3}}$	$98.56.\bar{154}.81.$	Hess., Césaro. Probably same as No. 2.
4.			$-\frac{19}{11}\ \frac{10}{11}$	$-\frac{10}{11}R^{\frac{8}{5}}$	$\bar{13}.\bar{3}.16.11$	Forms 4 to 8 inclusive were described by Irby. All were in striated zones, determined mostly from a single measurement, and are not established, especially as the author's study has shown the forms in this vicinity very subject to the formation of vicinal planes.
5.			$-\frac{32}{13}\ \frac{8}{13}$	$-\frac{8}{13}R3$	$\bar{16}.\bar{8}.24.13.$	
6.			$-\frac{23}{9}\ \frac{5}{9}$	$-\frac{5}{9}R^{\frac{17}{5}}$	$\bar{11}.\bar{6}.17.9.$	
7.			$-\frac{109}{41}\ \frac{22}{41}$	$-\frac{22}{41}R^{\frac{40}{11}}$	$\bar{51}.\bar{29}.80.41.$	
8.			$-\frac{139}{56}\ \frac{17}{28}$	$-\frac{17}{28}R^{\frac{52}{17}}$	$\bar{69}.\bar{35}.104.56.$	

Gnomonic Projection of Calcite Forms:—In order to study the relations of a large number of crystal forms it is necessary to represent them as projected upon a plane. The method here used to do this is known as the *gnomonic projection*. It is constructed as follows: A sphere is imagined as described about the centre of the crystal and a radius of the sphere is drawn normal to each face of the crystal. These radii are extended to intersect a plane tangent to the sphere at the point where the normal to the basal plane emerges, which plane is made to coincide with the plane of the construction. The points of intersection of the face-normals with the plane of projection represent the faces of the crystal. In such a projection the points representing all the faces of a zone—that is, all faces that are parallel to a single direction and whose mutual intersections are therefore parallel—lie along a straight line; and it is this property of the projection which is most useful in the study of so large a number of forms as we have to do with here.

Plate XVI is a gnomonic projection of the forms observed on Lake Superior calcite. It will be noted that the basal plane appears in the centre of the projection ; the rhombohedrons lie along six lines diverging at sixty degrees from the centre, positive and negative forms in alternate sectants ; the scalenohedrons lie within the sectants ; and the prisms are indicated by arrows at the margin pointing to their position, they not appearing as points since the normals to the prism planes are parallel to the plane of projection and hence do not intersect it.

It will at once be noted how certain zone lines stand out in the projection by reason of the number of planes distributed along them. A few words may well be devoted to the more important of these zones before the discussion of the individual forms is entered upon.

The most interesting zone, as being the most characteristic for this locality, is the one containing the planes δ., $-\frac{1}{2}$ R, b ⁝ $-\frac{1}{2}$ R 4; and 𝔛 ⁝, −4R $\frac{5}{3}$, with many others between. Very few calcites from Lake Superior can be found which do not show one or more of the scalenohedrons of this zone; and on many crystals three or four may be present. Of the nine scalenohedrons in the zone four are new and peculiar to this locality, and the form b⁝, $-\frac{1}{2}$R4, is, as vom Rath first stated, the characteristic form for the region.

A second zone, notable for its richness in forms, is that stretching between m· ,+4R, and ℑ⁝, +4R 2, containing in this portion nine positive scalenohedrons, of which all but three are here observed for the first time.

The zones containing the various rhombohedrons are of course conspicuous from the great number of planes lying in them, but other localities exhibit the same richness in these forms. The same is true of the zone stretching between two faces of p·, the unit rhombohedron, and beyond in both directions. This is the most important zone among the calcite forms as a whole, containing the commonest scalenohedrons of the species; it is well represented in our crystals by numerous forms, but does not have the peculiar significance for this region possessed by some other zones.

Of the other less important zones that may be traced among the forms of the projection, those of most interest are the ones connecting the many new scalenohedrons grouped about λ· ,$-\frac{8}{7}$R, and those near p· ,+R, and K:, +R3.

It is probable that the more important zone lines represent directions along which the molecular forces were particularly active during the growth of the crystal. The activity of these forces is controlled in a way not at all understood as yet by the environment of the crystal during growth; according as the conditions favor the one set of forces or the other, faces of forms in the various zones come to bound the crystal, and that variety of combinations is produced which is described by the term "crystal habit." Molecular forces acting along lines transverse to the chief zones are also effective in producing faces upon the crystal, and the points where two or more zones intersect, very commonly mark the most frequently occurring and best developed forms.

FORMS AND COMBINATIONS:—The forms given above in the table, will now be described, singly or in groups as their relative importance and mode of occurrence on the crystals demand.

No. 1, *Basal Plane.* This form appears very rarely on crystals on which positive scalenohedrons dominate the combination, but where negative forms control the habit it is rarely absent, though often small. It is generally bright, but appears sensitive to etching agents and is one of the first planes to become dull when the crystal is attacked.

These observations do not agree with those of Pumpelly* who says: "The basal termination on scalenohedrons of calcite is as rare on Lake Superior as elsewhere, and in the few instances where I have seen it, it lacks the polish which indicates perfect growth."

The form will be observed in various degrees of development in several of the drawings.

Nos. 2 to 6, *Prisms.* The prismatic development is notably rare on Lake Superior calcites. Figure 8, plate XII, reproduces a crystal of prismatic habit, as does figure 21, plate XIV. But these are exceptional types, and generally where prisms occur they are subordinate to other forms, as in figure 20, plate XV. The prism of the second order, $\infty P2$, was noted more often than was ∞R; but the commonest of the prism forms is the new one, ψ, $\infty R\,\frac{1}{9}^{1}$, which is shown in figure 3, plate XI, and elsewhere. Its faces, often rounded, were sharp and bright on many crystals, and the form may be taken as well established and as rather characteristic for the region.

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* loc. cit. p. 21.

Nos. 7 to 10. *Pyramids of second order.* These are of minor importance, none of them having been observed more than once. Of the two that are new, ω, $\frac{32}{9}$P2, is shown in figure 9, plate XIII; the other occurred on a crystal not here figured.

Nos. 11 to 16. *Positive rhombohedrons.* While rarely dominant, these forms are highly characteristic for the region, and are seldom entirely lacking. The steeper forms, Nos. 11, 12, and 13, are of rare occurrence.

m· ,+4R, is however the commonest form of all and plays an important part in the development of the crystals. Rarely very large, it is still present on almost every crystal, is always of the most perfect quality and its admirable reflections were very commonly used to orient the crystal for measuring. About it, as is well shown in the projection and in such crystals as are illustrated by figures 5 and 7, plate XII, are clustered many zones and forms, evidencing the importance of the form. Its characteristic deltoid or triangular shape may be seen in figure 14, plate XIII, and figures 20 and 24, plate XV.

k·, +$\frac{5}{8}$ R, occurs rather often as a narrow truncation of the obtuse edge of the common scalenohedron K:,+R3.

R· ,+2R. This new rhombohedron is the dominant form on a magnificent crystal of the Hubbard collection, shown in figure 6, plate XII. It was not observed elsewhere, but the size and perfection of the faces left nothing to be desired in its determination.

p· ,+R. This form occurs only less frequently than +4R on Lake Superior crystals, a notable fact since it is not a common form for most localities. Its faces are generally good, though sometimes dulled by etching. As it is the cleavage rhombohedron, it was always used to orient the forms—that is to determine whether positive or negative—and as few crystals are so fortunate as to have escaped some slight bruise, sufficient, with the easy cleavage of calcite, to develop cracks or to break off a corner, faces of +R were hardly ever absent even when not present as crystal planes.

Nos. 18 to 31. *Negative Rhombohedrons.*

δ· ,−$\frac{1}{2}$R, appears very frequently as a terminal plane, sometimes alone, and with plane faces,more often striated deeply by oscillatory combination with scalenohedrons of the principal zone, a feature not of course confined to this locality.

$\lambda\cdot$, $-\frac{8}{7}R$, occupies an important place in the zonal development of these calcites, and appears with sharp, plane faces on many crystals, examples of which may be seen in figure 5, plate XII, figure 10, plate XIII, and figure 16, plate XIV. It seems to be confined to crystals of negative scalenohedral habit.

The forms numbered 19, 21 to 25, and 27 are for the most part limited to a few crystals on which they form zones striking in the sharpness which these slightly differing forms may be recognized. Figure 1, plate XI, a beautiful specimen from the Bement collection, and figure 20 plate XV, from the same source, are the best representatives of this type; in others they merge together more or less, forming rounded surfaces with horizontal striations.

$\varphi\cdot$, $-2R$, is the most common of the negative rhombohedrons. It is generally of brilliant lustre, and its ordinary position, truncating the acute edge of the scalenohedron K:, $+R3$, as in figure 3, plate XI, makes its identification easy in many cases. Its appearance is very different on crystals of the negative scalenohedral type, such as shown in figures 9 and 13, plate XIII.

$\Gamma\cdot$, $-3R$, forms rhombohedral crystals, the polar edges obliquely truncated by $+R$, the lateral edges rounded by an indeterminate scalenohedron, which is often deeply etched.

$\triangle\cdot$,$-\frac{7}{2}R$, was observed on several crystals.

$\Pi\cdot$,$-8R$, occurs in a variety of combinations. See figures 24 and 22, plate XV, where it is the bearer of a simple combination of unusual type, the crystals being quite opaque from the abundance of inclusions as described above, page 165.

$\Sigma\cdot$, $-11R$, was observed only once.

No. 32. u:, $-\frac{2}{13}R4$. This new negative scalenohedron in the principal zone is of interest as occurring on several crystals as a narrow plane truncating the edge between the basal plane and the scalenohedron $-\frac{1}{2}R4$, in the manner shown in figure 23, plate XV.

Nos. 33 to 50. *Positive Scalenohedrons of the principal zone.* These forms fall naturally into two groups, comprising, 1st: those between two faces of $+R$ (see projection) Nos. 33 to 39; 2nd: those lying beyond $+R$ in the zone, Nos. 40 to 50. In the first group the forms are very prone to merge together, forming with $-\frac{1}{2}R$, a rounded surface giving a continuous train of reflections in the goniometer. The forms named were, however, well determined; some of them are nearly always present, as the terminations, with $-\frac{1}{2}R$, of crystals having the positive scalenohedral habit. Rarely the crystal is shortened in the direction of the chief axis, and the terminal planes become enlarged so as to give them the importance of dominant forms.

It is to forms of the second group, Nos. 40 to 50, that the crystals so frequently referred to as of positive scalenohedral habit owe their shape. The form K:, +R3, is generally the bearer of these combinations, as is well shown in figure 3, plate XI; upon it the steeper forms of the zone, including the prism of the second order ($\infty P2$) appear as a series of narrow faces parallel to the lateral edges, often merged into a striated, rounded surface. The same is true of the flatter forms which are, however, less numerous, forming a transition to +R and through this form to the series of the first group. Crystals of this habit, more or less modified by negative forms and rhombohedrons, are very abundant, comprising perhaps more than a third of those studied. To this type belonged all the crystals described by vom Rath. They are the characteristic product of the mines of the Ontonagon District, of which the old Minnesota and the National are among the best known. The perfection of symmetrical development of some of the calcites of this type, the abundance and brilliancy of their planes and their transparency combine to place them among the most remarkable crystals known to mineralogy.

H:, +R2, beside occurring as above described, was observed frequently with small, bright faces on crystals of negative type as shown in figure 17, plate XIV.

K:, +R3, is rarely absent from Lake Superior calcites. Either it is dominant as above, or it is in equally balanced development with negative forms, as in figure 1, plate XI, or it occurs as a subordinate form on crystals of negative habit, as in figure 13, plate XIII. In whatever manner it occurs, its faces are always of the finest, remaining bright after most of the other forms have suffered from etching.

P· , $+R\frac{14}{3}$. New, observed on two crystals not here figured.

U:, +R9, is figured by vom Rath as the dominant form on one of his crystals. Though not so observed by the writer, it was found on several specimens as a narrow face.

The remaining forms of this group were not observed except as subordinate members of the principal zone.

Nos. 51 to 60. *Positive scalenohedrons of the parallel zone, +4R to -2R.*

The interest attaching to this zone has been pointed out under a previous heading. Representatives of the zone are found on many crystals, and it appears specially characteristic of the water-clear specimens from the Central mine which, except for these forms, display a negative scalenohedral habit. Figure 2, plate XI, and figure 17, plate XIV, show typical combinations in which these forms are prominent and their relations will be best understood by examination of these drawings.

𝔘:, $+3R\frac{11}{9}$, stands apart from the rest of the group as falling within +4R in the zone. It was observed on but two crystals, one of which is shown in figure 5, plate XII. The faces were particularly bright and plane.

𝔍:, +4R2 was the most frequently observed of these forms; its bright faces occurred sometimes without any other member of the group, but generally between it and +4R is a series of the intermediate forms.

Nos. 52 to 57 are all new; Nos. 58 and 59 had been before observed by Hessenberg. Although these nine forms lie so near together their faces were always sufficiently distinct to give sharp reflections in the goniometer, and as all but one of them were observed at least once quite alone, each member of the very complete series may be accepted as established.

Nos. 61 to 69. *Positive scalenohedrons of various zones.*

U, $+2R\frac{7}{3}$, new to calcite, is a very common and characteristic form for the Lake Superior crystals. Always with brilliant faces, and lying in a zone with +4R, its recognition is generally easy. Figure 4, plate XI, shows it as the dominant form of the combination; more often it is subordinate in size as in figure 2, plate XI, figure 7, plate XII, and figure 14, plate XIII.

𝔙:, $+\frac{8}{5}R3$. Observed but once on the crystal shown in figure 9, plate XIII.

P, $+2R\frac{10}{3}$. New—a small face observed only on the crystal shown in figure 7, plate XII.

M, $+\frac{4}{5}R3$, New—well developed on one crystal as shown in figure 9, plate XIII.

Z, $\frac{4}{5}R\frac{5}{3}$. New—observed on several crystals, but generally somewhat rounded and tending to pass over to the next form. Shown in figure 17, plate XIV.

N, $+-\frac{8}{11}R2$. New—a common form on crystals of negative habit, with smooth faces, often quite large. It is nearly in the zone of the acute edge of $-\frac{1}{2}R4$, which makes it easily recognizable in most cases Shown in figure 6, plate XII, and in figure 19, plate XIV.

𝔴:, $+\frac{1}{2}R\frac{11}{3}$; 𝔟, $+\frac{3}{5}R\frac{31}{9}$; 𝔞, $+\frac{6}{7}R\frac{28}{9}$; These three new forms lie in a zone between +R3 and +R. They occur with small, bright faces, sometimes altogether as in figure 5, plate XII, or separately, as in figure 7, plate XII, on a few crystals of negative scalenohedrål habit.

Nos. 70 to 78. *Negative scalenohedrons of the zone* $-\frac{1}{2}R4$ *to* $-4R\frac{5}{3}$

This zone has already been pointed out as the most characteristic for the region. Many crystals are combinations exclusively of forms of this zone, a feature the more marked, as negative scalenohedrons as a rule play a subordinate part in the crystallization of calcite, and though certain of the forms here prominent are of common occurrence elsewhere, on no other crystals does the zone as a whole assume any importance.

b:, $-\frac{1}{2}R4$, is the form which fills the most noteworthy role in the development of Lake Superior calcites. Its faces are usually plane and lustrous, giving good reflections in the goniometer. But in crystals where its planes are of relatively large size, it is often much facetted and broken by numerous vicinal planes, most of them very near it in position, and some of sufficiently constant recurrence to be established as independent forms. They will be discussed on a subsequent page. It was the occurrence of these forms on the crystals measured first by Hessenburg, and re-examined by Irby, that occasioned the large discrepancies in their results. Only by examination of a larger suite of crystals could their true character be determined.

$-\frac{1}{2}R4$ appears often as the bearer of the combination, as in figures 23 and 19, plate XV. More frequently it is in balanced development with the form -2R2, as in figures 15 and 18, plate XIV. In such crystals its bright faces are in marked contrast to the deeply striated faces of the steeper form. It is this type of crystal that is found most abundantly at the present day, chiefly from the Quincy mine and others in the Pewabic belt. Quite as often it is found as a subordinate form, both on crystals of a negative habit, as in figures 1 and 2, plate XI, and on those of positive habit, as figure 3, plate

XI. In short, it occurs in all possible varieties of development, and is rarely absent.

𝔉: ,$-\frac{4}{5}R3$, is far less common than the last, but is still a frequent form. Figure 12, plate XIII, shows it as the dominant form of a combination, and it plays the same part in Irby's figure 6. This, however, is rare, and it is more apt to appear as a subordinate face of the negative zone on crystals of positive scalenohedral habit, like that figured by Des Cloizeaux. Its faces are of good quality.

F,$-R\frac{8}{3}$. New—observed but once, as shown in figure 11, plate XIII.

A,$-\frac{8}{7}R\frac{5}{2}$ New—observed but once, as a striated face, but well determined by the zonal relations, as shown in figure 6, plate XII.

I,$-\frac{5}{4}R\frac{12}{5}$. New—observed but once as a narrow face in the chief zone, as shown in figure 14, plate XIII.

Y,$-\frac{20}{13}R\frac{11}{5}$, was first observed by vom Rath on Bergen Hill calcite, and had not again been recognized. Here it is of frequent occurrence, sometimes, as in figure 4, plate XI, of dominant character, more often as a narrow face in the zone. Faces generally deeply striated or dull.

𝔭: ,$-2R2$, is only less common than $-\frac{1}{2}R4$, with which it is nearly always associated. Its faces are not always striated, as described above, but are plane and lustrous.

B,$-\frac{28}{11}R\frac{13}{7}$. New—observed on two crystals as a narrow face in the zone, as shown in figure 17, plate XIV.

𝔛: ,$-4R\frac{5}{3}$, was often observed, and sometimes with large faces; always of good lustre. Shown in figure 8, plate XII, and in several of vom Rath's figures.

Nos. 79 to 87. *Negative scalenohedrons of other zones.*

The three forms, Nos. 79, 80 and 81, belong to a zone which is of peculiar interest from its nearness, both, in position and direction to the principal negative zone just described. It is as though some disturbing force had been active during crystal growth, pulling the faces slightly out of their normal positions. It is doubtless to such abnormal forces that we are to ascribe the formation of the so-called "vicinal planes," and as such, these are to be regarded, though they are here sufficiently definite in their occurrence to be recognized as independent forms.

C,$-\frac{4}{7}R\frac{10}{3}$, was one of the many planes, near to $-\frac{1}{2}R4$, observed by

Irby on a single crystal. It alone has been confirmed by the study of the larger series at the author's command. It is a very common form, either as the bearer of rich combinations like those shown in figure 5, plate XII, and in figure 17, plate XIV; or as a vicinal to $-\frac{1}{2}R4$ in the shape of facets as shown in figure 19, plate XIV, and in figure 7, plate XII. Figure 10, plate XIII, reproduces a crystal of special interest as exhibiting all the forms of this abnormal zone without any of the typical forms being present. The crystal sufficiently defines the character of the two new forms of the zone, I·, $-\frac{7}{8}R\frac{55}{21}$, and D, $-\frac{5}{4}R\frac{11}{5}$, neither of which was observed more than twice.

No. 82, E, $-\frac{7}{22}R4$. New—observed on but one crystal, as a narrow truncation of the edge between 0P and C, $-\frac{4}{7}R\frac{10}{3}$, as shown in figure 5, plate XII. The faces were somewhat uneven.

No. 83, K, $-\frac{5}{4}R\frac{6}{5}$, is a new form of special interest, and is very characteristic for the region. Many crystals had been examined which were very nearly cubical in outline, but their faces so rounded and broken that it was impossible even to say whether the dominant form was a rhombohedron or a scalenohedron. At length the crystal reproduced in figure 13, plate XIII, was sent to the author as a very rare form from the Ridge mine, and it gave a satisfactory solution of most of the problematic crystals. The dominant form was the scalenohedron in question, $-\frac{5}{4}R\frac{6}{5}$; it approximates so closely to the rhombohedron $-\frac{7}{5}R$, whose angles are within less than a degree of 90 degrees, that the cubical appearance of the rough crystals on which it occurred is readily understood. Owing to the selection of the point of view, this effect is unfortunately rather poor in the drawing. On this crystal the planes were highly polished and gave excellent reflections; it was not observed in measurable condition on other specimens.

No. 84, $\mathfrak{b}$, $-\frac{32}{31}R\frac{3}{2}$, and No. 85, $\mathfrak{c}$, $-\frac{16}{17}R\frac{3}{2}$, are new forms in a zone with $-\frac{8}{7}R$ and $-\frac{1}{2}R4$. The crystal on which they were observed was etched in parts, and it is possible that these are etch faces, which would in a measure explain their complex symbols. They are shown in figure 12, plate XIII. The second of the two was also observed on other crystals.

No. 86, $\mathfrak{f}$, $-\frac{14}{13}R\frac{13}{7}$, a new form, and No. 87, $\mathfrak{g}$:, $-R\frac{5}{3}$, occur, together with No. 85, in a zone on three crystals of the type shown in figure 16, plate XIV. The large development of these forms on several splendid crystals, and the perfect quality of their faces establish them as good forms despite the complex symbols which must be employed to satisfy the measured position. The crystal figured is also remarkable for its twinning, described below.

RÉSUMÉ:—A brief review of the foregoing descriptions shows the following facts. Of the 85 crystal forms observed by the author on Lake Superior calcites, 59 have not been before described from that locality, and 32 are new to the species.

The forms most prominent by reason of their common occurrence, are $-\frac{1}{2}R4$, $+R3$, $+4R$, $+R$, $-2R2$, and $0P$.

As peculiarly characteristic of the locality, the following forms may be named: $-\frac{1}{2}R4$, $+4R$, $+2R\frac{7}{3}$, $+\frac{8}{11}R2$, $-\frac{8}{7}R$, $\infty R\frac{11}{9}$, and the forms having the general symbol $4Rn$.

Two general types of habit are recognized in which the positive and the negative scalenohedrons dominate respectively, but there are many crystals of intermediate habit in which both groups of forms occur in balanced development. The prismatic and rhombohedral habits are rare.

There are but few exceptions to the rule that the crystal planes are of good quality, and give excellent reflections for measurements.

The formation of vicinal planes is most marked in the neighborhood of the form $-\frac{1}{2}R4$.

TWINNING:—Twinned crystals are a common feature of Lake Superior calcites. Twinning occurs according to two laws: first, the twin and composition face is $0P$; second, the twin and composition face is $-\frac{1}{2}R$. Of these two laws the first is exemplified in a far greater number of cases.

A simple twin on $0P$ is shown in figure 20, plate XV, reproducing a remarkably perfect and symmetrical crystal from the Bement collection. In this crystal the twinning has not resulted in the appearance of any re-entrant angles as is so often the case; it is simply expressed in the horizontal boundary dividing the upper and lower portions of the crystal, and in the reversal of the ordinary alternate relation of the faces above and below. Such simple twins were also shown by the fine crystal in the U. S. National Museum at Washington, by a splendid specimen in the Hubbard collection, and by the crystal in the Harvard Cabinet, already mentioned as of unusual dimensions. They do not, however, seem to be of common occurrence.

A much more frequent expression of this twinning, is that shown in figure 17, plate XIV. Here a thin band or lamella through the centre of the crystal is alone in twinning position, the portions above and below it retaining their normal relation. This layer is parallel to 0P, and occupies almost invariably the very centre of the vertical dimension of the crystal. Sometimes it is of no greater thickness than a very thin sheet of paper, and may be traced as a fine hair-line or seam on the glassy surface of the crystal. Figure 17 shows such a case, the cross-section accompanying it aiding to show the interruption in the crystal growth caused by the twinning. The various faces are cut off sharply by this almost invisible boundary, some forms, however, such as m· , continuing their growth beyond the reentrant caused by the twin lamella.

Again, the twin lamella may be of greater thickness, showing crystal planes on its surface as in figure 19, plate XIV. And in very exceptional cases the lamella grows outward along the edges, beyond the boundaries of the main crystal, producing wing-like segments of a second crystal in twin position to the parts of the first above and below. Two such specimens were studied, one of which, a superb crystal over two inches in height, from the Hubbard collection, is figured in figure 16, plate XIV. The other was from the Pumpelly collection, and was much smaller and less perfect, but was bounded by the same rare planes as the first named. Very often, too, several lamellae in alternate twin position are intercalated in the crystal centre.

The occurrence of this twin seam or "Naht" was first described by vom Rath, and is a characteristic feature of the Lake Superior crystals, not known elsewhere.

Twins on the face of $-\frac{1}{2}$R are not rare, and often take the form shown in figure 18, plate XIV, the distortion of the faces of -2R2, there indicated, being a common feature. This form of twin was observed only on crystals of negative type, chiefly from the Quincy mine; the finest example seen was a very large specimen in the Hubbard collection not here figured. Many crystals show numerous twin lamellae parallel to $-\frac{1}{2}$R, and on some such, sent to me by Dr. Hubbard, he pointed out that the summits were injured in such a way as to suggest a blow or impediment during growth sufficient perhaps to produce a pressure on the crystal through which the twinning was induced in the well-known manner. In a few cases these fine twin lamellae traverse the crystal in such numbers and with such regularity as to produce a marked striation on the bounding faces.

STRIATION AND ETCHING:—Both phases of crystal imperfection are commonly illustrated on these calcites. Several cases of characteristic striation have already been cited, for example, that parallel to the combination edges of the planes of the principal negative zone; this affects all the faces of the zone, but particularly the forms b: and Y.

Other examples may here be noted. In figure 5, plate XII, striations are well marked parallel to the edge between λ· and C. In figure 14, plate XIII, v-shaped striations will be seen on m· parallel to its intersection edges with the faces of 4Rn. Deep striations are frequent parallel to the edges of intersection of N with b: or its vicinals. In figure 2, plate XI, is shown a horizontally striated face lying between m· and U; it is found to be produced by the oscillatory combination of the forms θ :, $+4R\frac{11}{9}$, and Π: , $+3R\frac{11}{9}$. In the same way, in figure 9, plate XIII, the striation face between 𝔅: and C is caused by combination of ω and m.

The effects of etching have not been introduced into the figures, though many of the crystals studied showed interesting samples of that process. As the faces produced by it are almost always rounded or rough, and of variable position, they cannot for the most part be given places as independent forms. Some of the features may, however, be noted.

Many crystals of positive habit show among their terminal planes more or less even faces lying slightly out of the principal zone. This is probably an etch form, as measurements on various crystals gave very discordant results for its position. The crystals which show this form have very often suffered a deep corrosion of the upper parts of the faces of K:, +R3; these parts are roughened and pitted while the remainder of the crystal is unharmed. The portion of the face affected is generally bounded below by a curve which is symmetrically located on all the faces.

On one fine specimen from the collection of Mr. Whiting, deep triangular etch figures appeared on the faces of the form U,$-2R\frac{4}{3}$; unfortunately the crystal was too large to mount on the goniometer, and the position of the sharp faces which bounded the pits within, could not be determined.

In the description of the form K, $-\frac{5}{4}R\frac{6}{5}$, mention was made of the many rough and rounded crystals whose form was probably determined by it. The rough surfaces of these crystals give evidence of having been produced by etching processes.

Nothing is known as to the agents producing these etching effects in this region; nor can they be correlated with any particular period of deposition, or mode of formation.

COURSE OF INVESTIGATION:—The crystallographic studies, the results of which have here been given in brief form, have extended over a period of nearly three years, during which new material has constantly been obtained. Some of the new forms discovered have already been announced in the pages of Goldschmidt's Krystallographische Winkeltabellen, Berlin, 1897, p. 396, and table, pp. 82-86, but many more have been added to the list since the publication of that work. It will be noted that the measurements and tables of angles on the basis of which the new forms have been established, are not given in this paper. Those who desire to consult these data are referred to a paper shortly to appear in the Zeitschrift für Krystallographie, where a full discussion will be given.

The measurements were made for the most part on a goniometer with two circles (Goldschmidt Model 1895), which proved itself especially effective in the study of the complex crystals in hand. Small crystals were generally available, and where such were not to be had, and specimens too large to be mounted on the two-circle instrument were to be measured, recourse was had to the ordinary horizontal goniometer (Fuess, No. 2.)

Mineralogical Museum, Harvard University, July 1898.

EXPLANATION OF PLATES.

Fig. 1. Bement Coll. (171). Locality not stated, but similar crystals in the coll. come from Owl Creek Vein, Copper Falls Mine. Transparent, yellowish, 1 inch high.

Fig. 2. Hubbard Coll. (86). Central Mine. Colorless, ½ inch high.

Fig. 3. Harvard Cabinet, (33). Minnesota Mine, Ontonagon district. Transparent, yellowish, 1 inch high.

Fig. 4. Whiting Coll. (9). Colorless, ¼ inch high.

Fig. 5. Whiting Coll. (3). Colorless, minute. The face C which occurs on this crystal, and is referred to twice on page 179, is the face running diagonally down from p-.

Fig. 6. Hubbard Coll. (268). Colorless, 3 inches high.

Fig. 7. Whiting Coll. (54). Colorless, 1 inch high.

Fig. 8. Munich Cabinet. Reproduced from Zeit. für Kryst., *loc. cit.* p. 589.

Fig. 9. Brush Coll. (127). Twin lamella parallel to 0P. Colorless, 1½ inch high.

Fig. 10. Pumpelly Coll. (168). Phœnix Mine. Colorless, etched, small.

Fig. 11. Harvard Cabinet (129). Some faces etched, copper inclusions. Under ½ inch.

Fig. 12. Hubbard Coll. (258). Minute, colorless, etched in part.

Fig. 13. B. F. Chynoweth (259). Ridge Mine, Ontonagon district. Yellowish, 1 inch high.

Fig. 14 Whiting Coll. (18). Water-clear, 2 inches high.

Fig. 15. Harvard Cabinet (30). Central Mine. "Shadow Crystal," with copper inclusions, 1 inch high.

Fig. 16. Hubbard Coll. (266). Yellowish, 2½ inches high. Twin on 0P.

Fig. 17. Vaux Coll. (136). Water-clear, 2½ inches high (with vertical section). Twin lamella parallel to 0P shown.

Fig. 18. Hubbard Coll. Quincy Mine. Twin on $-\frac{1}{2}R$, copper inclusions, 2 inches high.

Fig. 19. Hubbard Coll. (75). (Drawn in orthographic projection.) Twin on 0P. Yellowish, 1 inch high.

Fig. 20. Bement Coll. (164). Owl Creek Vein, Copper Falls Mine. Yellowish crystal, 2 inches high. Twin on 0P.

Fig. 21. Harvard Cabinet (143). Colorless, minute.

Fig. 22. Bement Coll. (165). Ridge Mine, Ontonagon district, 1 inch high, black from inclusions.

Fig. 23. H. L. Smyth (124). Colorless, ¼ inch high.

Fig. 24. W. D. Schoonmaker (139). One corner of large crystal 2 inches high, transparent.

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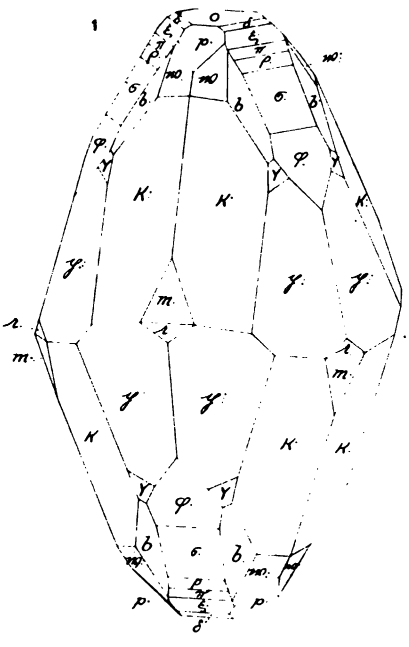

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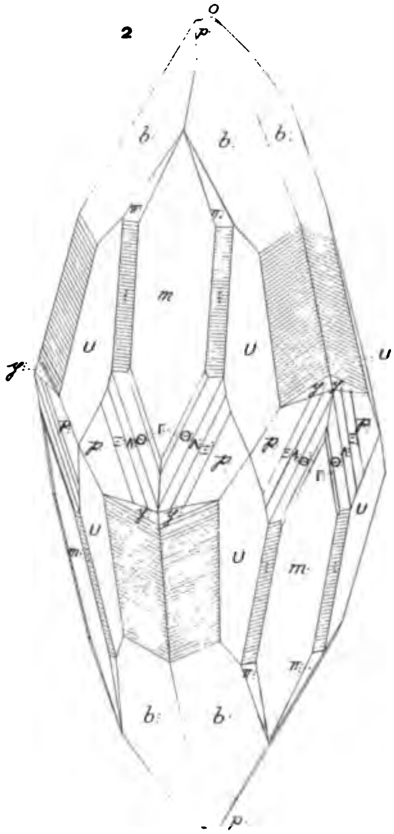

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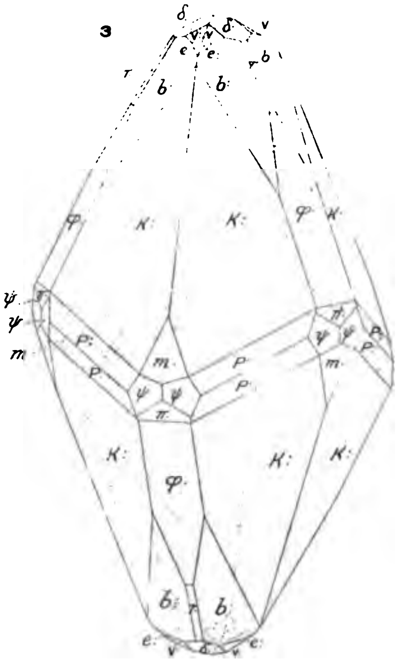

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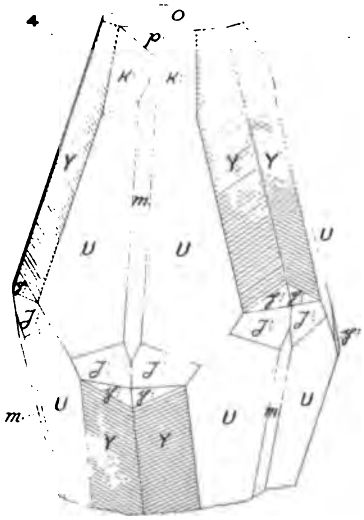

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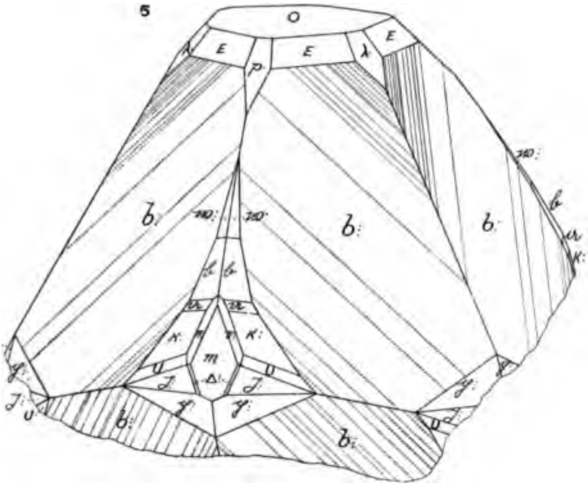

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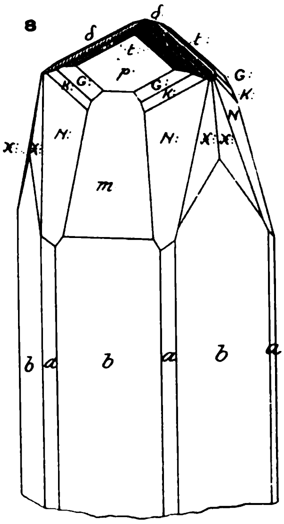

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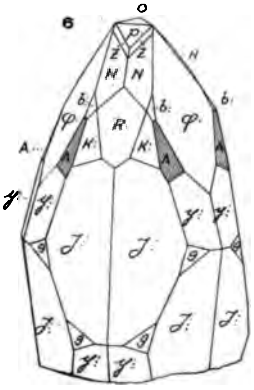

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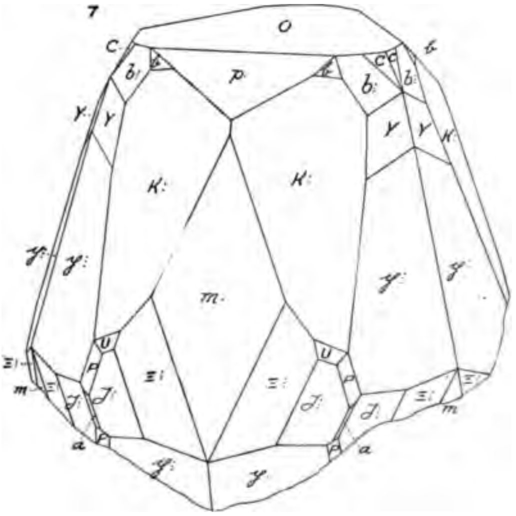

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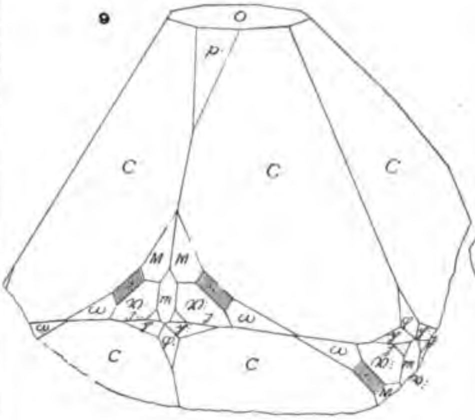

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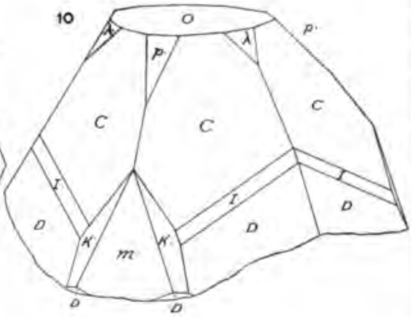

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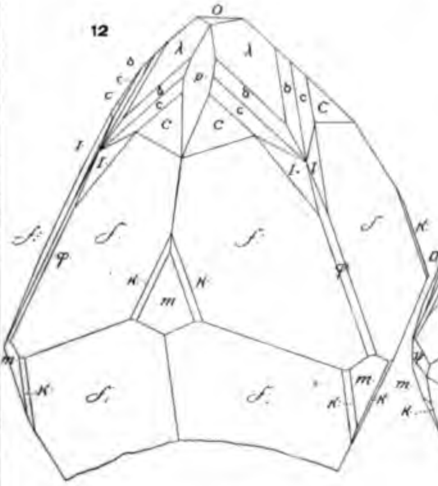

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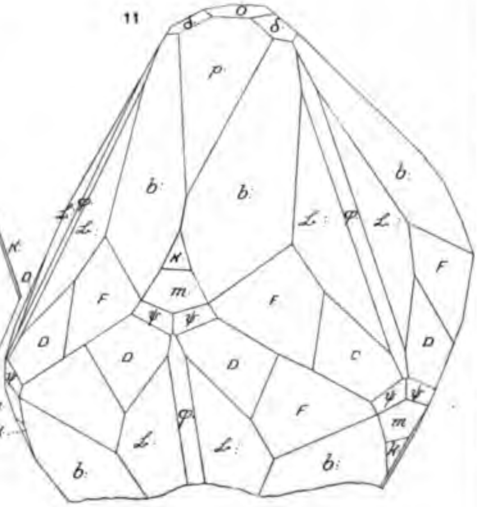

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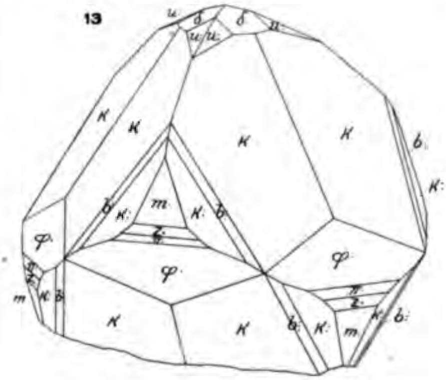

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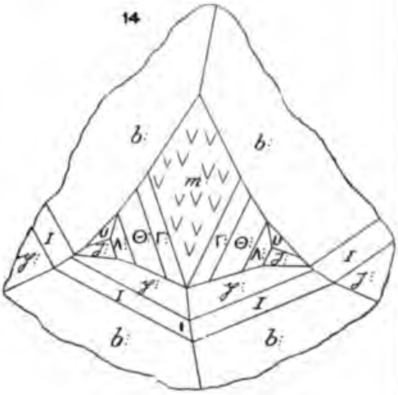

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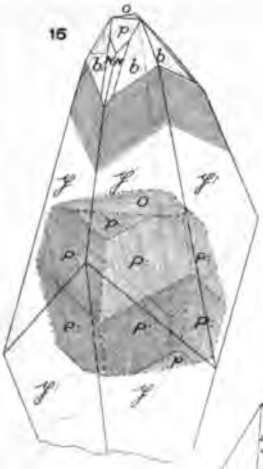

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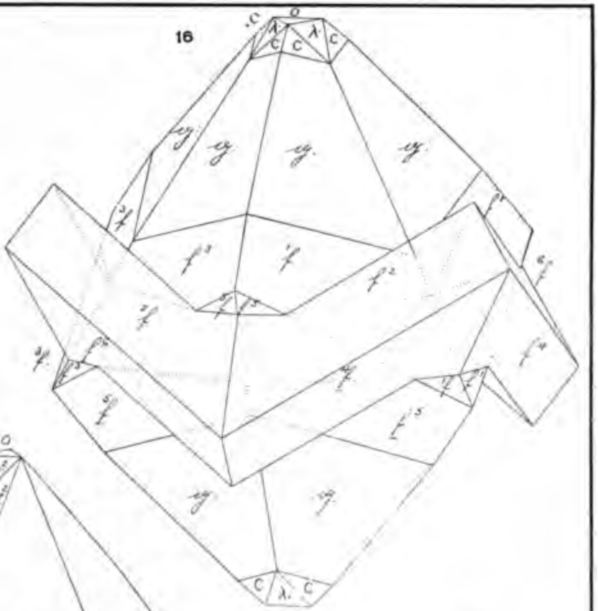

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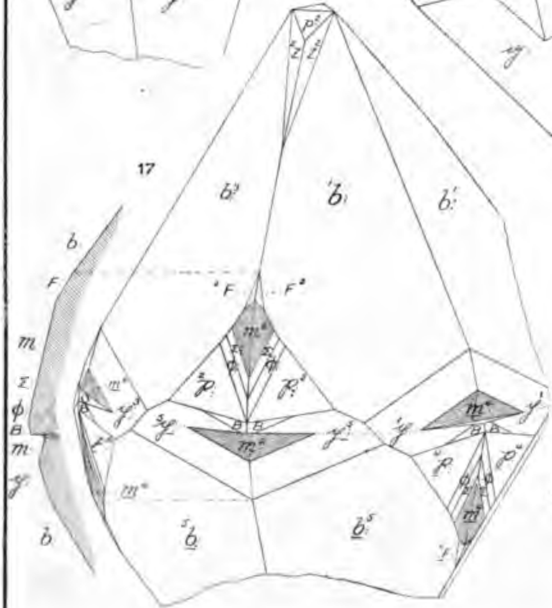

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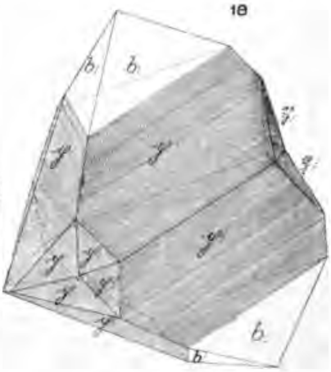

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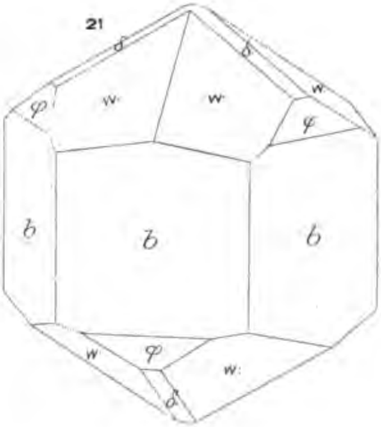

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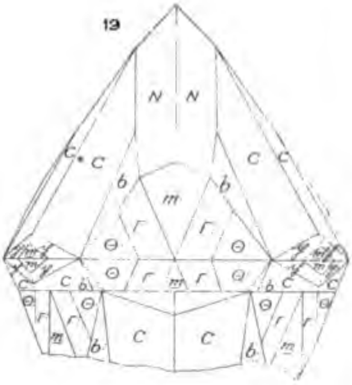

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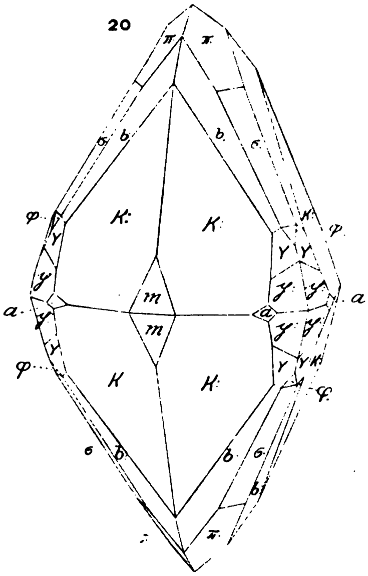

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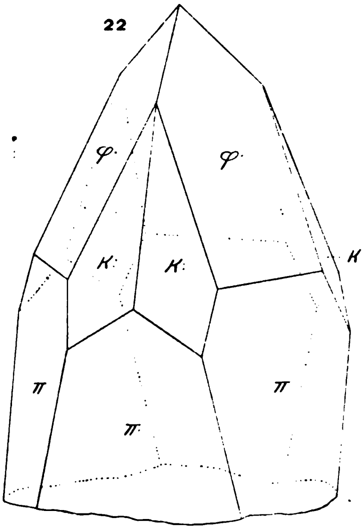

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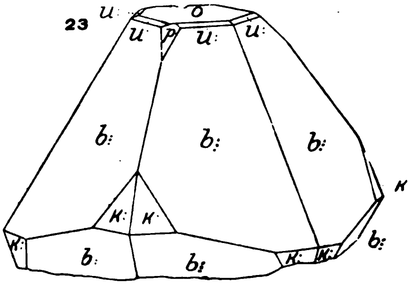

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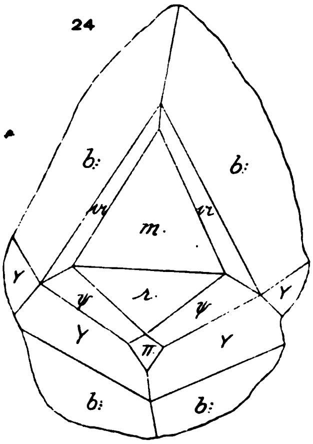

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